AD NUMBER

AD867924

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; MAR 1970. Other requests shall be referred to Air Force Rocket Propulsion Lab, Attn: RPPR/STINFO, Edwards AFB, CA 93523.

AUTHORITY

Air Force Rocket Propulsion Lab ltr dtd 29 Sep 1971

AD 867924

SINGLE-CHAMBER STOP/START SOLID ROCKET MOTOR (U)

FINAL REPORT

VOLUME II, APPENDIXES

Contract F04611-68-C-0063

Report AFRPL-TR-69-50 March 1970

[redacted] this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPPR/STINFO), Edwards, California 93523.

aerojet solid propulsion company

A DIVISION OF AEROJET GENERAL

205

ACCESSION for	
CFSTI	WHITE SECTION ☐
DDC	BUFF SECTION ☑
UNANNOUNCED	☐
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
DIST.	AVAIL. and/or SPECIAL
2	

Report AFRPL-TR-69-50

"When U. S. Government drawings specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto."

Report AFRPL-TR-69-50

SINGLE-CHAMBER STOP/START

SOLID ROCKET MOTOR

FINAL REPORT

VOLUME II APPENDIXES

CONTRACT F04611-68-C-0063

Charles T. Levinsky
Norman P. Mittermaier
Albert O. Hardrath

~~In addition to security requirements which must be met,~~ this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPPR/STINFO), Edwards, California 93523.

AIR FORCE ROCKET PROPULSION LABORATORY
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

APPENDIX A

STOP/START SOLID ROCKET MOTOR STRESS ANALYSIS

STOP/START TWENTY-PULSE STRESS ANALYSIS

I. DISCUSSION

A. SUMMARY OF RESULTS

The following table provides a summary of the margins of safety of all the significant structural items.

They are based on pressure loads which incorporated a 1.25 factor of safety. The allowables are based on the material properties at the maximum thermal excursion the part will experience, (Ref. Section III-A).

TABLE 1.1

Part	Drawing Number	Minimum Margin of Safety	Page
Throat, Pintle	1147001	+.03	3.1.1-1
Throat, Retainer	1147003	+.015	3.1.2-2
Coupling	1146997	+.17	3.1.3-2
Piston Retainer	1146999	High	3.1.4-1
Piston, Pintle	1146998	+.33	3.1.5-3
Strutted Housing	1146995	+0.0	3.1.6-5
Entrance Cap, Pintle	1147005	+.09	3.1.7-1
Exit Cone Pins	1147016	+.51	3.1.8-1
Nozzle Support	1147008	+.31	3.1.9-2
Nozzle Throat	1147012	.34	3.2.5.1
Outer Nozzle Assembly	1147006	High	3.1.11-1

Section 3.2.0 represents the results of a finite element computer analysis of the pintle and shroud nozzle components.

Figures 3.2.1.0 and 3.2.5.0 are computer output plots of the pintle and shroud. They identify the geometry, materials used in the assembly, nodal point and element locations.

The entire ejection load and piston load is transferred across Section A-A of the SSRM coupling (Ref. Figure 3.2.1.1). Considering thermal excursions at the end of the firing, a high margin of safety is shown. This confirms the analysis performed on Page 3.1.3.1 early in the design.

Sections C-C and B-B (Ref. Figure 3.2.2.1) of the throat retainer must transfer ejection loads on the AG Carb 101 to the piston. Using material allowables at 200°F, the temperature expected at 750 seconds, a high margin of safety is shown.

Tension across the retainer shank is again due primarily to ejection loads on the AG Carb 101. Section A-A, (Ref. Figure 3.2.2.1) at the undercut, has a 0.13 margin of safety at 750 seconds after ignition.

The stresses on the AG Carb 101 are shown in Figures 3.2.4.1 through 3.2.4.6. Sections in shear due to pressure and thermal loads are shown in Figure 3.2.4.1 through 3.2.4.3. The shear allowable is estimated at 2700 psi. This produces a M.S. = 0.24 at 8 seconds.

Hoop stress distribution is shown graphically in Figures 3.2.4.4 through 3.2.4.6 when the thermal gradient is maximum. The compressive stress on the inner surface is maximum and produces a M.S. = 0.0. However, this is conservatively based on tensile allowables. Compression allowables of graphites are appreciably higher than tensile allowables.

The shroud nozzle geometry is shown in Figure 3.2.5.0. The hoop stress distribution on the pyro insert at 10 seconds is shown in Figures 3.2.5.1 through 3.2.5.3. Again compression on the inner fiber produces a minimum M.S. =0.34. Conservatively, it is based on pyro tensile allowables.

Figure 3.3.2 summarizes the results of the propellant grain analysis. The minimum M.S. =0.19 in the bond.

B. METHOD OF ANALYSIS

The motor was checked initially using conventional methods and pressure loadings. This analysis (Ref. Section III-A), utilizes a 1.25 factor of safety and material properties expected at the end of the firing.

The initial analysis is two fold in purpose:

(1) It evaluates geometry and material changes on the design.

(2) It provides a reasonable geometry for the thermal stress analysis.

The latter analysis, (Ref. Section III-B) incorporates the final thermal map and pressure distribution. It is based on a 1.0 factor of safety.

AGC computer program No. E11405, "Finite Element Analysis of Solids with Nonlinear Material Properties", was used. This analysis is run with thermal distributions expected at the following times in the duty cycle.

1. t = 8.0 seconds

   Maximum Gradient in the Pintle Insert.

2. t = 10.0 seconds

   Maximum Gradient in the Shroud Insert.

3. t = 750 seconds

   Maximum Thermal Excursion in the Pintle.

This analysis, which is time-consuming because of all the details and computer turnaround time, serves two purposes:

1. Verifies the initial analysis.

2. Incorporates the effects of the varying thermal distributions in the structure.

A grain analysis was run utilizing existing parametric design curves. The grain was checked for the following load conditions:

1. Firing at Ambient Temperatures.

2. Thirty-day Storage at 0°F.

II. DESIGN CRITERIA

A. LOADS

Pressure

MEOP	550 psia
Actuator	3000 psia
F.S.	1.25 yield

Design Loads

$p_D = 1.25 \times 550 = 690$ psia

$p = 1.25 \times 3000 = 3750$ psia (Hydraulic System)

B. MATERIAL PROPERTIES

Ref. Page 2.3 through 2.8

C. GEOMETRY

Ref. Figure 2.1 and 2.2

Figure 2.1 is the computer plot of the aft end of the pintle.

Figure 2.2 is the computer plot of the shroud portion of the nozzle.

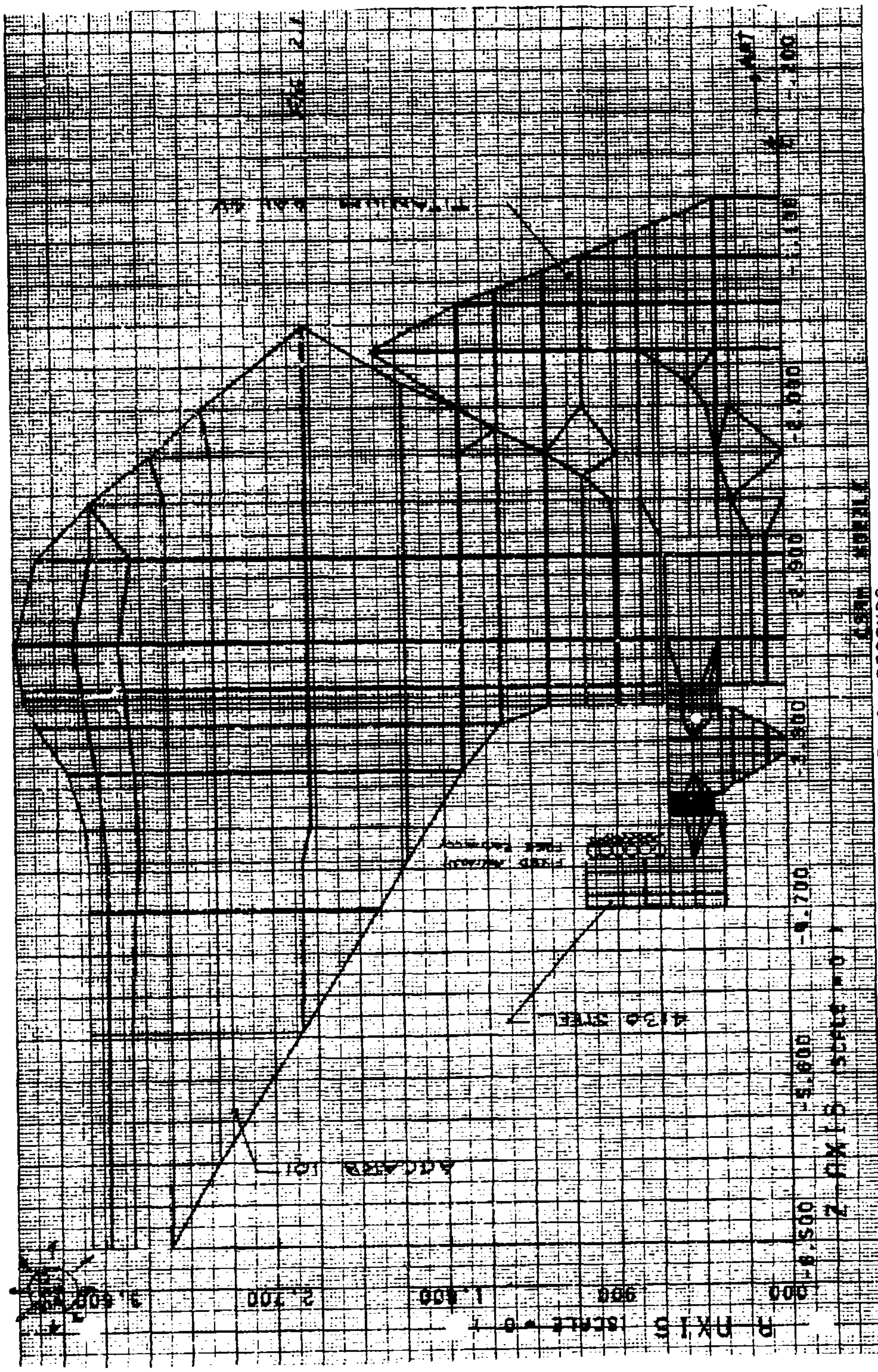


Figure 2.1

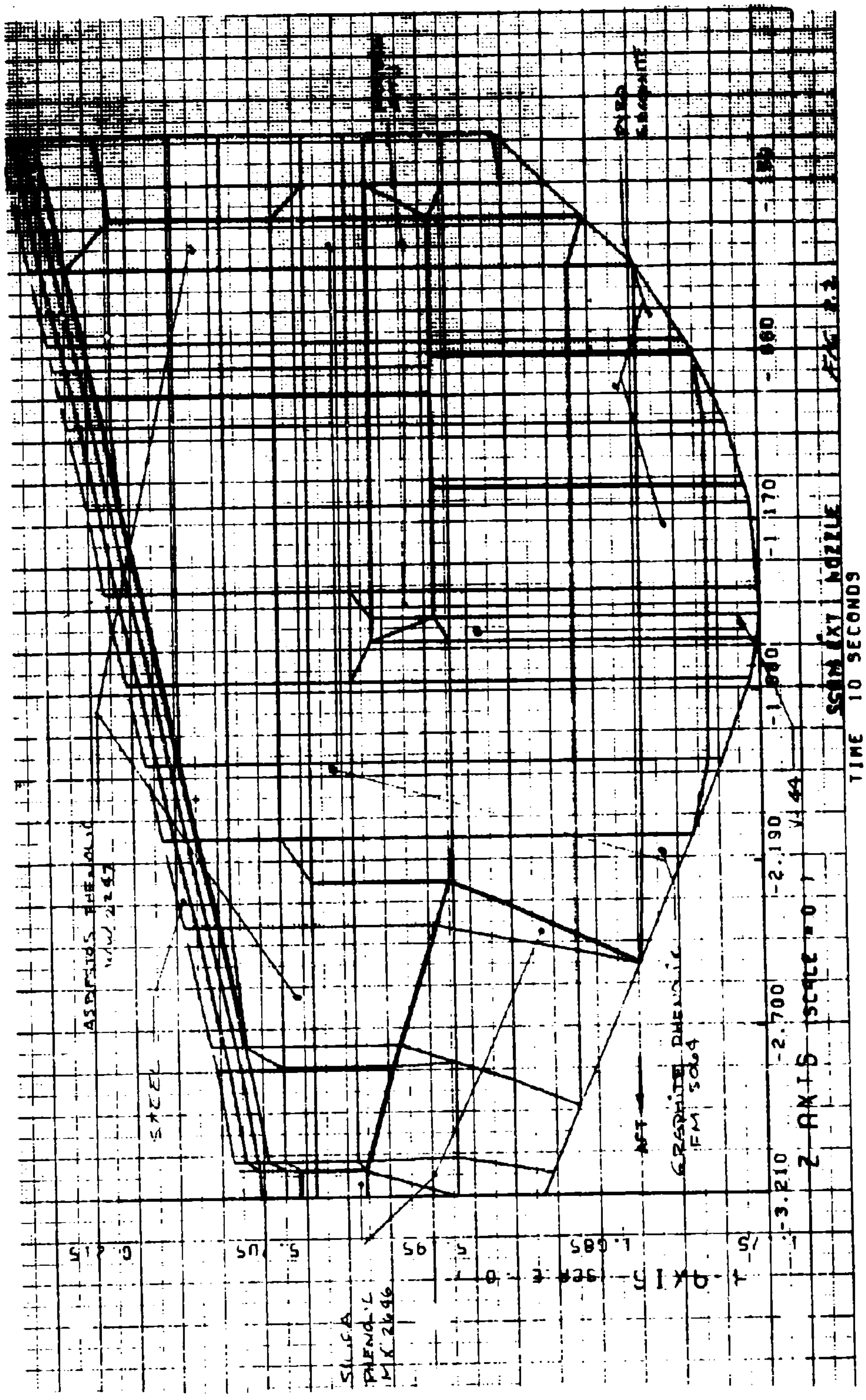


Figure 2.2

PYRO GRAPHITE

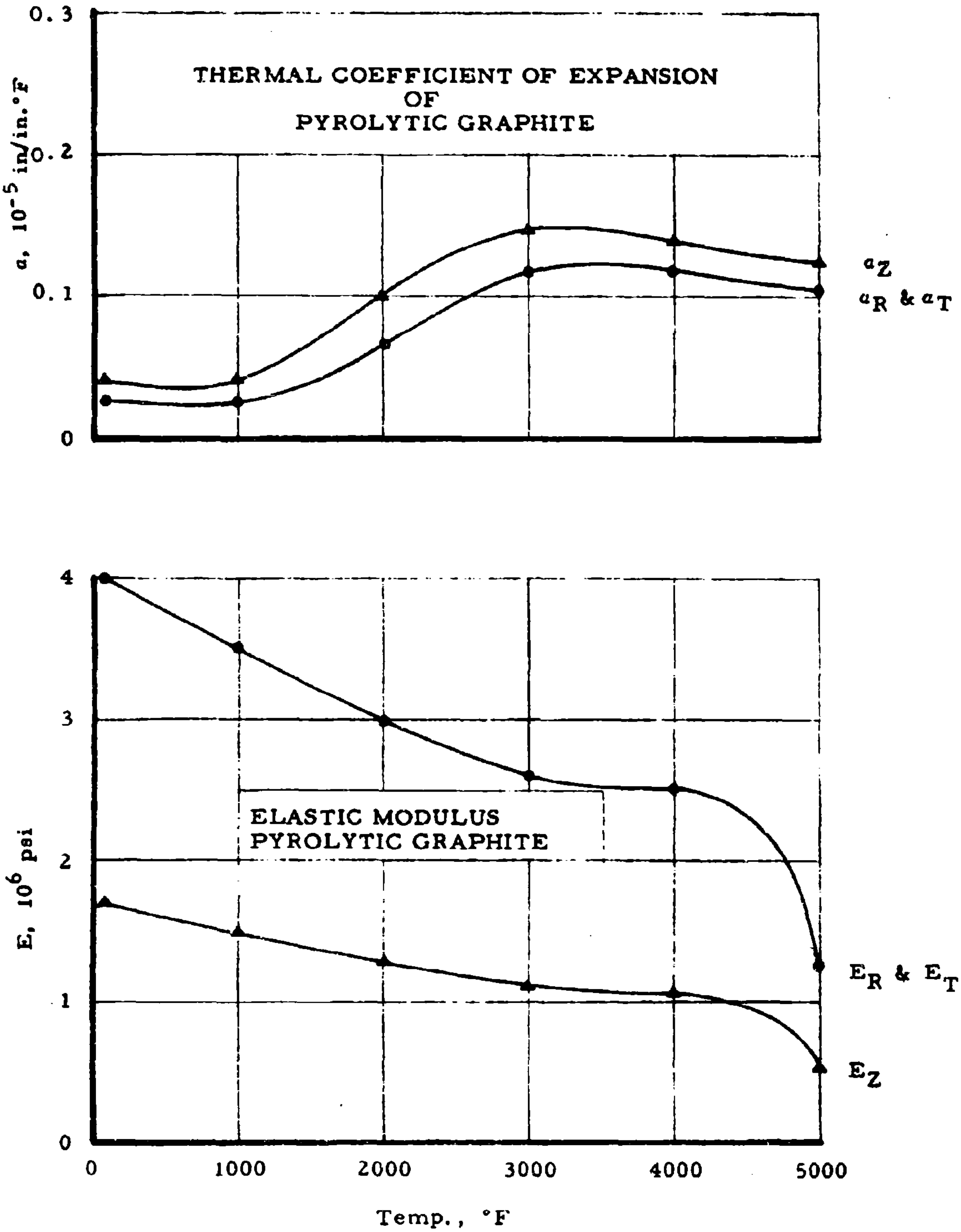


Figure 2.3

MOLDED ATJ

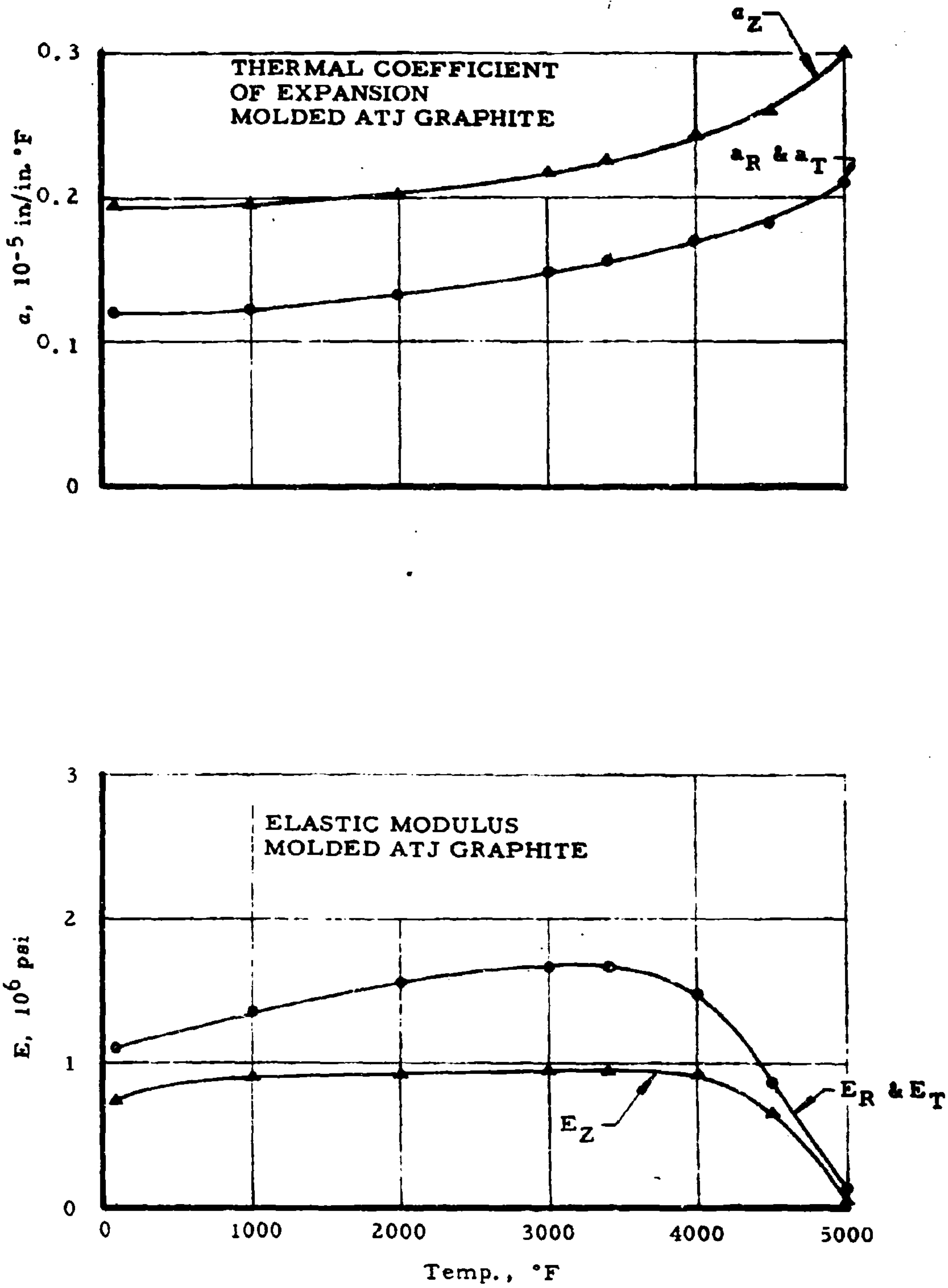
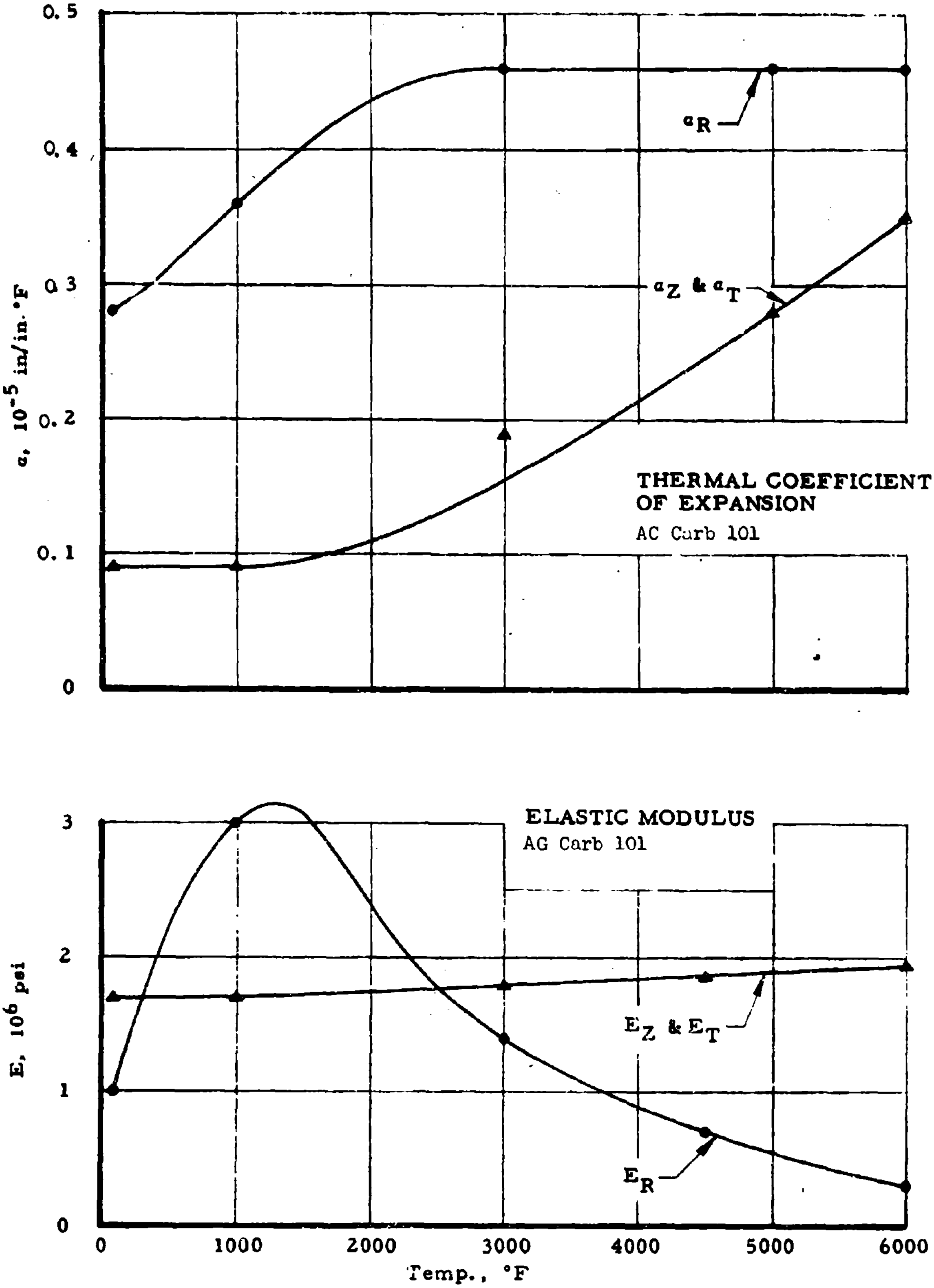
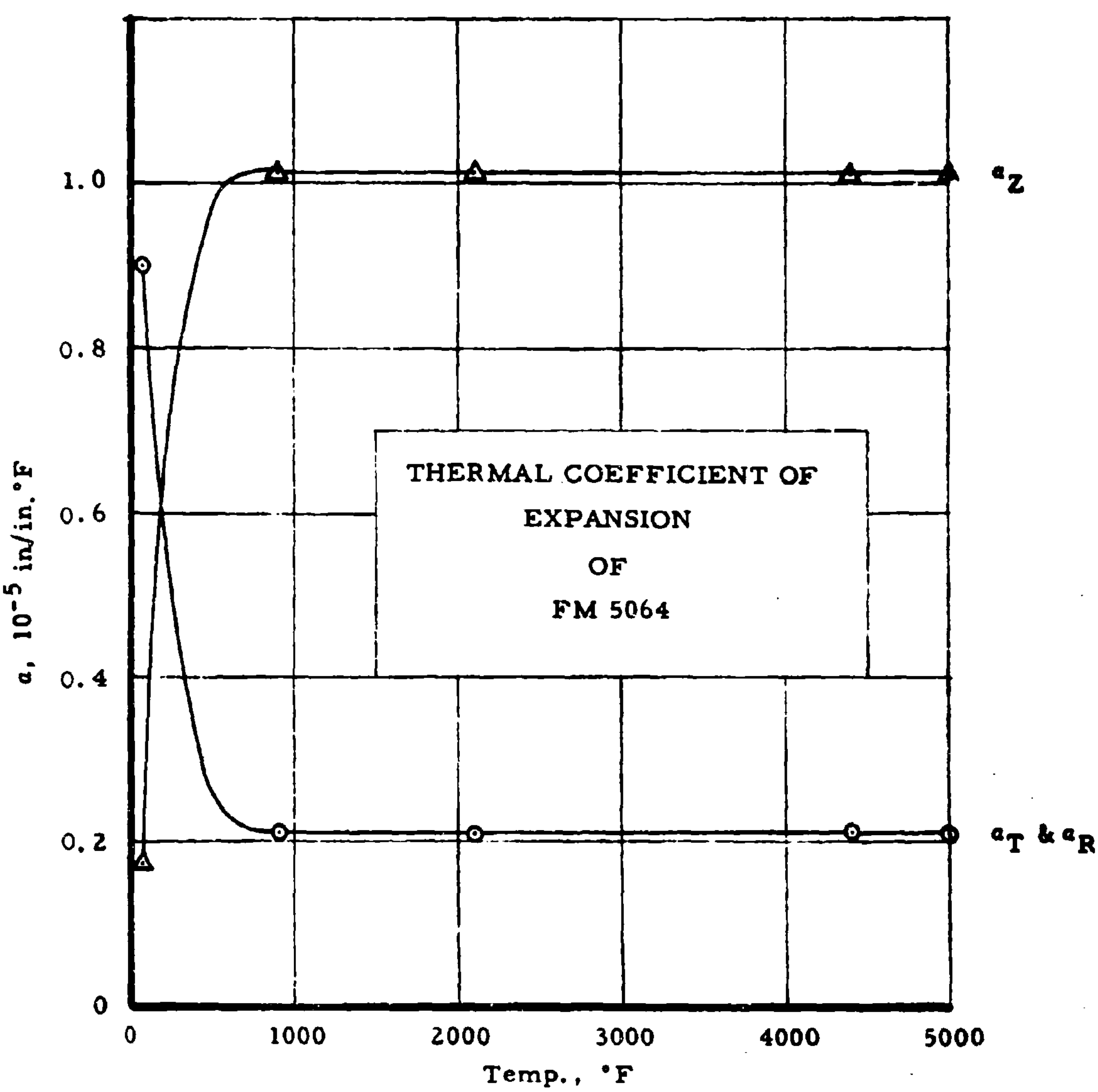


Figure 2.4



0.5
0.4
0.3
0.2
0.1
0
α, 10^{-5} in/in.°F
α_R
α_Z & α_T
THERMAL COEFFICIENT OF EXPANSION
AC Carb 101
ELASTIC MODULUS
AG Carb 101
3
2
1
0
E, 10^6 psi
E_Z & E_T
E_R
0
1000
2000
3000
4000
5000
6000
Temp., °F

Figure 2.5



1.0
0.8
0.6
0.4
0.2
0
α, 10^{-5} in/in. °F
0
1000
2000
3000
4000
5000
Temp., °F
α_Z
α_T & α_R
THERMAL COEFFICIENT OF
EXPANSION
OF
FM 5064

Figure 2.6

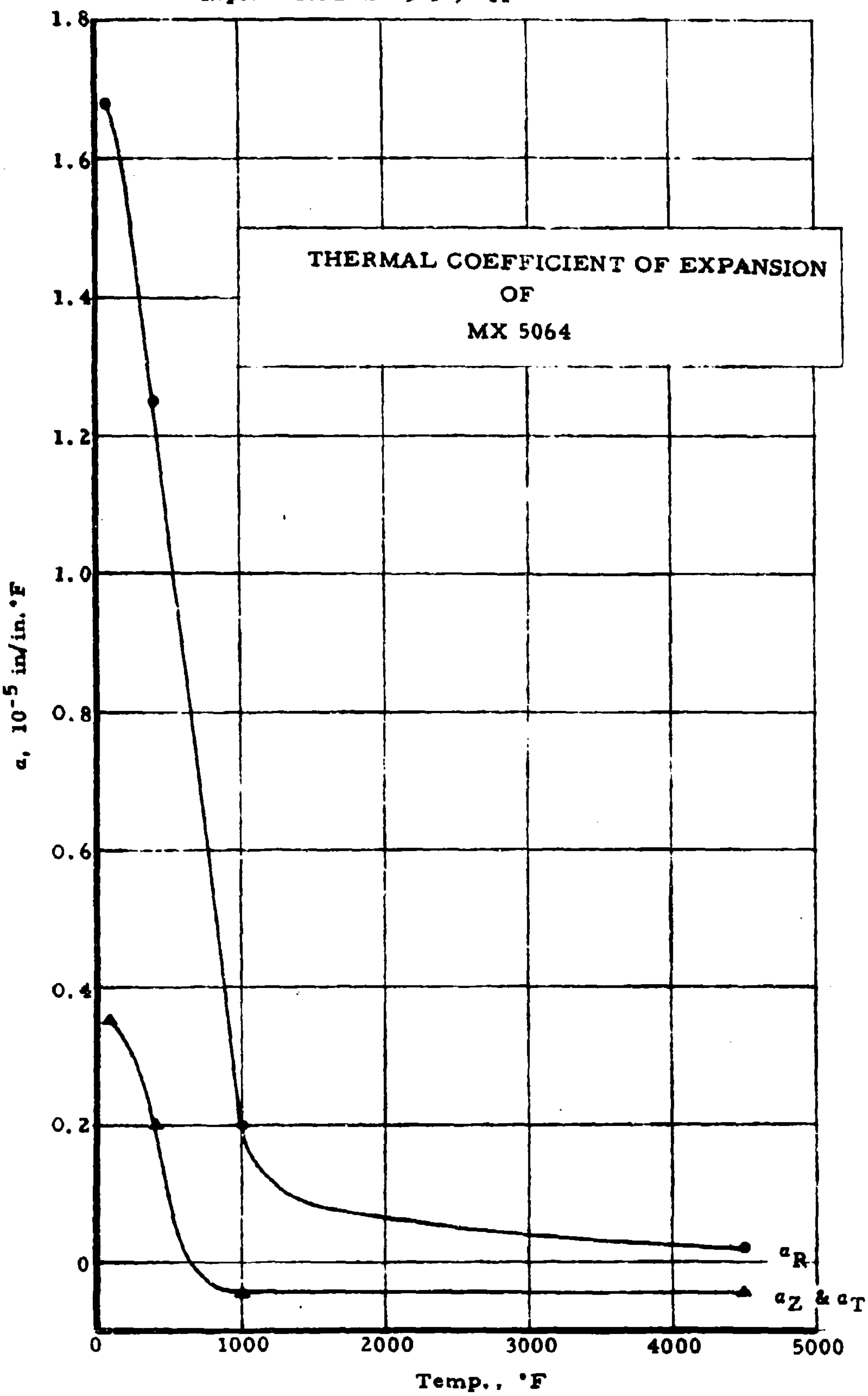

THERMAL COEFFICIENT OF EXPANSION
OF
MX 5064
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
α, 10^{-5} in/in.°F
0
1000
2000
3000
4000
5000
Temp., °F
α_R
α_Z & α_T

Figure 2.7

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCE-0000-11

REPORT NO.
PAGE III-2 OF
DATE
WORK ORDER
DATE

SUBJECT
20 PULSE

BY
CHK. BY

TABLE OF CONTENTS

TABLE OF NOTATION

f = PREDICTED OR CALCULATED STRESS, PSI
F = ALLOWABLE STRESS, PSI
P = TOTAL LOAD, #
p = PRESSURE, PSI

REPORT NO.
PAGE
DATE
SUBJECT
WORK ORDER
DATE

SEC 3.1.1 SSRM — THROAT, PINTLE

BY H. EFRON CHK. BY

THROAT, PINTLE DWG 1147001, AG CARB 101

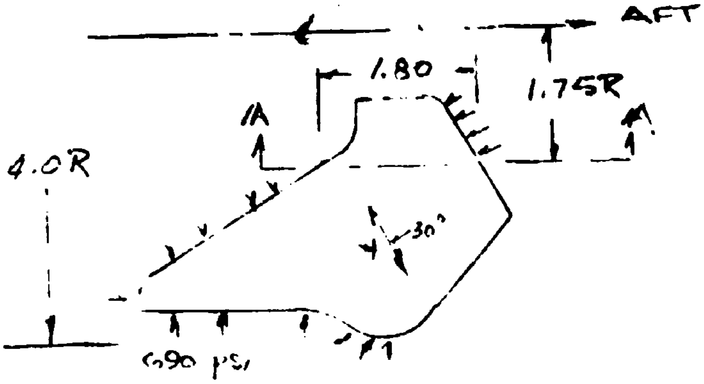


FIG 3.1.1

@ SEC A A

SHEAR

$f_s = \frac{3}{2} \frac{P_{EJF}}{A}$

$P_{EJF} = 11000\pi$ #

$A = 2\pi(1.75)(1.80) = 6.30\pi$

$= \frac{3(11000)}{2(6.30)} = 2620$ psi

$F_s = 2700$ psi @ ROOM TEMP

$M.S. = \frac{2700}{2620} - 1 = \underline{.03}$

BENDING

$f_b = \frac{6M}{t^2}$

$M = .5(4.0 - 1.75)\frac{11000}{2(1.75)} = 3540$ in-#/in

$= \frac{6(3540)}{(1.8)^2} = 6550$ PSI

$F_T = 10{,}000 \cos^2 30° = 7500$ PSI

$M.S. = \frac{7500}{6550} - 1 = \underline{.15}$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0000-11 | REPORT NO. | PAGE 11.1 OF

SUBJECT: SEC 3.1.1 SSRM—THROAT PINTLE | DATE | WORK ORDER

BY: H. EFRON | CHK BY | DATE

THROAT, PINTLE   DWG 1147001, AG CARB 101

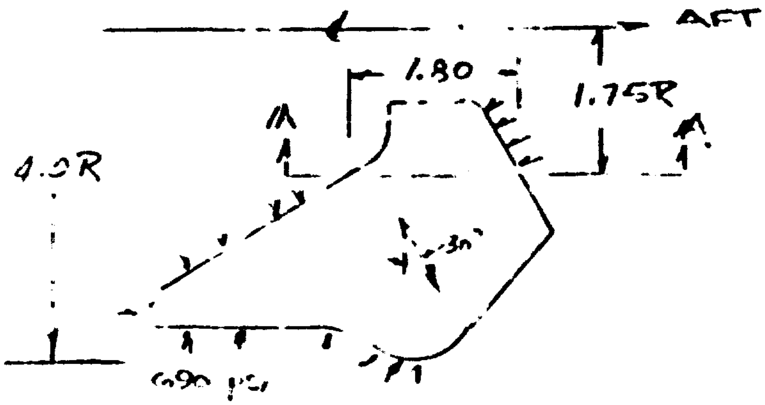


FIG 3.1.1

@ SEC A A

SHEAR

$f_s = \frac{3}{2}\frac{P_{FJp}}{A}$

P_{FJp} 11000#

$A = 2\pi(1.75)(1.80) = 6.30\pi$

$= \frac{3(11000)}{2(6.30)} = 2620$ psi

$F_s = 2700$ psi @ ROOM TEMP

$M.S. = \frac{2700}{2620} - 1 = .03$

BENDING

$f_b = \frac{6M}{t^2}$

$11?.5(4.0-1.75)\frac{11000}{[illegible](1.75)} = 3540$ in-#/in

$= \frac{6(3540)}{(1.8)^2} = 6550$ psi

$F_b = 10{,}000\cos^2 30° = 7500$ psi

Preceding Page Blank

$M.S. = \frac{7500}{6550} - 1 = .15$

SUBJECT: SEC 3.1.2 SSRM – RETAINER, THROAT

BY: H. EFRON | CHK. BY | DATE | WORK ORDER | DATE

RETAINER, THROAT DWG # 1127003 , TITANIUM 6AL-4V

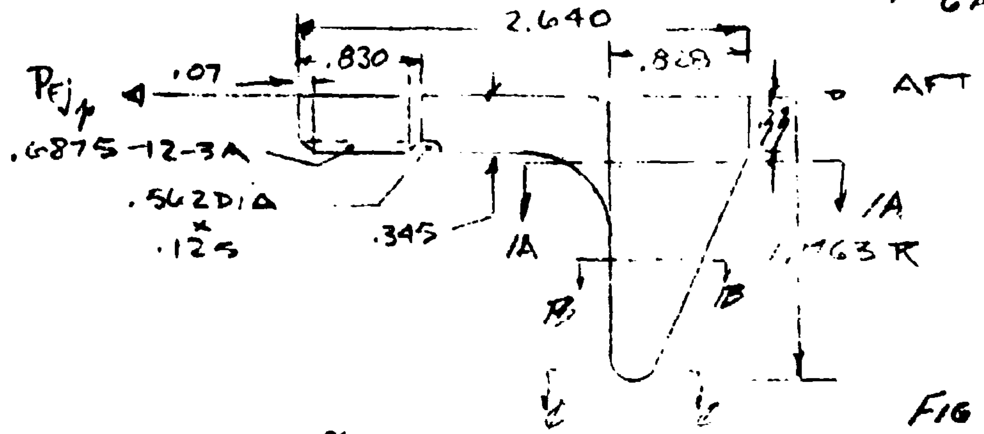


FIG 3.1.2

@ SEC /A-/A

SHEAR

$$f_{SHR} = \frac{3}{2}\frac{P_{EJ_p}}{A}$$

$P_{EJ_A} = 11000\pi$ # REF. p 3.1.1.1

$A = 2\pi \,.25(.828) = .58\pi \text{ in}^2$

$$= \frac{11000}{.58} \times 1.5 = 28,500 \text{ psi}$$

$F_s = 100,000$ psi

$$M.S. = \frac{100.0}{28.5} - 1 \text{ Hi}$$

BENDING

$$f_b = \frac{6M}{t^2}$$

$t \approx .9$

$$M < P_{EJ_p}(1.763-.35)/.7\pi = \frac{11000(1.413)}{.7} = 22,200 \text{ in-}\#/\text{in}$$

$$= \frac{6(22200)}{.9^2} = \frac{133200}{.81} = 165,000 \text{ psi}$$

$F_b = 150,000 + 20,000 = 170,000$ psi

$$M.S. = \frac{170}{165} - 1 = +.03$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

ABCS-0600-11

SUBJECT	REPORT NO.	PAGE
SSRM - RETAINER, THROAT		DATE
		WORK ORDER
BY H. EFRON	CHK. BY	DATE

@ THREADS .6875-12-3A

TENSION @ U'CUT

$$f_T = \frac{P_{EJ_p}}{A_T}$$

$P_{EJ_p} = 11000\#$ REF: p 3.1.1.1

$A_T = \frac{\pi}{4}(.562)^2 = .08\pi \ in^2$

$$= \frac{11,000}{.08} = 137,500 \ psi$$

$F_T = 150,000$ psi

$$M.S. = \frac{150.0}{137.5} - 1 = \underline{.09}$$

SHEAR REF FIG 3.1.2

$$f_s = \frac{P_{EJ_p}}{A_s}$$

$A_s = \pi(.562)(.5)(.830 - .125 - \frac{2}{12} - .14)$

$= .398(.5)(.562) = .112\pi^2$

$$= \frac{11000}{.112} = 98,500 \ psi$$

$F_s = 100,000$ psi

$$M.S. = \frac{100.0}{98.5} - 1 = .015$$

SUBJECT

SSRM - Retaining Throat

BY H. [illegible]

CHK BY

@ Sec. B-B, R = 1.0" & t = .50", Ref. Fig. 3.1.2

SHEAR

$f_s = \frac{3}{2}\frac{P}{A}$

$P = p\pi(4.0^2 - 1.0^2) = 15\pi\, 690 = 10350\pi$

$A = 2\pi R t = 1.0\pi$

$= \frac{3(10350)}{2} = 16{,}700$ psi

$F_s = 100{,}000$ psi

$M.S. = \frac{100}{16} - 1 = $ High

BENDING

$f_b = \frac{6M}{t^2}$

$M = \frac{P}{2\pi R}(1.763 - 1.0) = \frac{10350(.763)}{2(1.0)}$

$= 3940$

$= \frac{6(3940)}{(.5)^2} = 94{,}500$ psi

$F_b = 150{,}000 + 20{,}000 = 170{,}000$ psi

$M.S. = \frac{170.0}{94.5} - 1 = .80$

@ Sec. C-C, R = 1.732 & t = .25

SHEAR

$f_s = \frac{3}{2}\frac{P}{A}$

$P = p\pi(3.0^2 - 1.732^2) = 13\pi\, 690$
$= 9000\pi$ #

$A = 2\pi(1.732)(.25) = .866\pi\, in^2$

$= \frac{3(9000)}{2(.866)} = $ [illegible]

$F_s = 100{,}000$

$M.S. = \frac{100.0}{[illegible]} - 1 = $ Hi

SUBJECT: SEC 3.1.3 SSRM - COUPLING

BY: H. EFRON | CHK. BY | DATE

COUPLING DWG 1146997
4130 STL, COND C3, H.T. $F_{tu} = 180{,}000$ psi

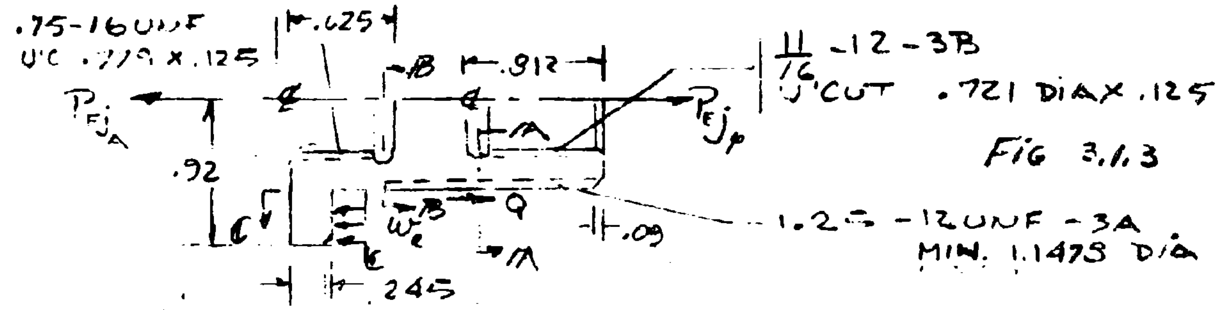


FIG 3.1.3

LOADS: 1. DUE TO CHAMBER PRESSURE: $p_D = 690$ psi

$P_{Fj_p} = p_D \pi (4.0^2 - .29^2)$ REF 3.2.1 DWG 1147003

$= 690\pi (16.0 - .09) = 11{,}000\pi$ #

$w_e = \dfrac{P_{Fj}}{A}$ $A = \pi(.92^2 - .579^2) = .52\pi$

$= \dfrac{11{,}000}{.52} = 21{,}200$ psi

** 2. DUE TO ACTUATOR PRESSURE: $p_A = 3750$ psi

$P_{Fj_A} = p_A \pi (1.25^2 - .75^2) = 3750\pi$ #

$Q = \dfrac{P_{Fj}}{2\pi R} = \dfrac{3750}{1.125} = 3330$ #/in

THREADS 11/16-12-3B

$f_s = \dfrac{P}{A}$

$P = 11{,}000\pi$ #

$A = \frac{11}{16}\pi (.912 - .09 - .125 - \frac{2}{12}^{*})(.5)$

$= .148\pi$

$= \dfrac{(11{,}000)}{(.148)} = 74{,}000$ psi

$F_s = 100{,}000$ psi   M.S. $= \frac{100}{74} - 1 = .35$

** REF: DWG #

* 1st 2 LAST THD INEFFECTIVE

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

REPORT NO.

PAGE II.3.2 OF

AGC9-0000-11

DATE 6/24/68

SUBJECT SSRM - Coupling

WORK ORDER

BY H. EFRON

CHK. BY

DATE

@ SEC A-A REF. FIG III

TENSION:

$f_T = \frac{P_{EJ}}{A}$

$P_{EJ} = 11{,}000$ # REF: ¶ 3.1.1.1

$A = \pi(.57^2 - .36^2) = .20$ IN^2

$= \frac{11{,}000}{.20} = 55{,}000$ psi

$F_T = 180{,}000$ psi

$R_T = \frac{f_T}{F_T} = \frac{55}{180} = .31$ STRESS RATIO

BENDING:

$f_b = \frac{6M}{t^2} K$

$M = \frac{.5 P_{EJ} (.57 - .36)}{(.57 + .36)\pi} = \frac{.11(11{,}000)}{1.03}$

$= 1180$ in-#/in

K = .9 SINCE SOME OF THE MOMENT (M) ROTATES THE AFT TUBE

$t = .5739 - .3605 = .2134$

$= \frac{6 \times .9 \times 1180}{(.2134)^2} = 140{,}000$ psi

$R_B = \frac{f_B}{F_B}$

$F_B \cong 180{,}000 + 80{,}000 = 260{,}000$

$= \frac{140}{260} = .54$

COMBINED STRESS:

$M.S. = \frac{1}{R_T + R_B} - 1 = \frac{1.0}{.85} - 1 = \underline{\underline{.17}}$

@ Sec B-B

Tension

$f_T = \dfrac{P_{FJ_P} + P_{FJ_A}}{A}$

$P_{FJ_P} = 11{,}000\pi^{\#}$ REF: p 7
$P_{FJ_A} = 3{,}750\pi^{\#}$
$A = \pi(.57^2 - .389^2) = .173\pi$

$= \dfrac{14{,}750}{.173} = 86.000$ psi

$F_T = 180{,}000$ psi

M.S. $= \dfrac{180}{86} - 1 = \underline{1.1}$

Bending: due only to actuator load

$f_b = \dfrac{6M}{t^2}$

$M = \dfrac{.5 P_{FJ_A}(.579 - .389)}{\pi(.389 + .579)}$

$P_{FJ_A} = 3750\pi^{\#}$ REF p 31.1

$= \dfrac{.095(3750)}{.968} = 370$ in-#/in

$f_b = \dfrac{6(370)}{(.19)^2} = 64{,}000$ psi

$F_B = 180{,}000 + 80{,}000 = 260{,}000$

Combined Stress

$R_T = \dfrac{f_T}{F_T} = \dfrac{86}{180} = .48$

$R_B = \dfrac{f_B}{F_B} = \dfrac{64}{260} = .24$

M.S. $= \dfrac{1}{\Sigma R} - 1 = \dfrac{1}{.72} - 1 = +\underline{.39}$

AEROJET-GENERAL CORPORATION SACRAMENTO • CALIFORNIA

AGCS-0890-11

REPORT NO.

SUBJECT SSRM - COUPLING

DATE 6/25/69

WORK ORDER

BY H. EFRON

CHK. BY

DATE

@ SEC C-C $t = 1.25/2 = .625$

BENDING

$f_b = \frac{6M}{t^2}$

$M = P_{EJ_V} .5(.92-.625)/1.25\pi$

$= \frac{11000\pi .15}{1.25\pi} = 1320^{in\text{-}\#}/in$

$t = .245$ REF: FIG 3.1.3

$f_b = \frac{6(1320)}{(.245)^2} = 132,000$ psi

$F_b = 180,000 + 80,000 = 260,000$ psi

$M.S. = \frac{180}{132} - 1 = \underline{.37}$

SHEAR

$f_s = \frac{3}{2}\frac{P}{A}$

$P = P_{EJ_V} = 11000\pi^{\#}$ REF: p 3.1.1

$A = 2\pi r(.245)$

$= 1.25(.245)\pi = .307\pi$

$= \frac{3(11000)}{2(.31)} = 54,000$ psi

$F_{SHR} = 100,000$ psi

$M.S. = \frac{100}{54} - 1 = \underline{.85}$

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

AGC8-0080-11

SUBJECT	REPORT NO.	DATE
SSRM - COUPLING		6/25/68
BY H. EFRON	CHK. BY	DATE

THREADS .75 - 16UNF - 3B

$$f_s = \frac{P_{ej_A}}{A}$$

$P_{ej_A} = 3750\pi$ *

$A = .5(.75)\pi(.625 - .125 - \frac{3}{16})$ *

$= .375\pi(.375) = .375^2\pi \text{ IN}^2$

$$= \frac{3750}{.375^2} = 26600 \text{ psi}$$

F_s: 100,000 psi

$$M.S. = \frac{100{,}000}{26{,}600} - 1 = \underline{\underline{Hi}}$$

* 1st & LAST THREAD INEFFECTIVE

SUBJECT SEC 3.1.4 SS.R.M RETAINER, PISTON

BY H. EFRON CHK. BY DATE

RETAINER, PISTON DWG 1146939

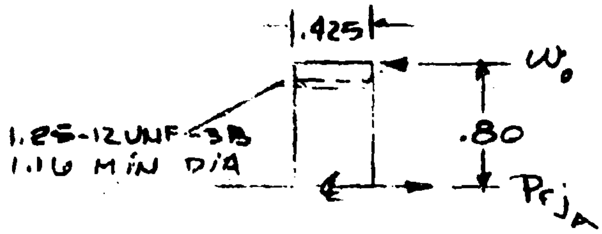


FIG 3.1.4

THREADS : D = 1.16 MIN DIA

$f_{SH} = \frac{P_{FJ_A}}{A}$

$A = \frac{\pi D}{2}(.425 - \frac{2}{12}) =$

$= \frac{1.16}{2}(.3)\pi = .174\pi$

$P_{FJ_A} = 3750\pi^{\#}$ REF p 3.1.1

$= \frac{3750}{.174} = 21,500$ psi

$F_{SHR} = 100,000$ psi

M.S. $= \frac{100}{22} - 1 =$ Hi

RING ROTATION - BENDING

$f_b = \frac{McR}{I}$

$M = \frac{(.75 - .625)}{\pi(.75 + .625)}\left[3750\pi\right]$

$= \frac{.125(3750)}{1.375} = 340$ in-#/in

$c = .212$

$I = \frac{bh^3}{12} = \frac{.125(.425)^3}{12} = \frac{7.75}{96} \times 10^{-3} = .81 \times 10^{-3}$

$R = .63$

$= \frac{340(.212)(.63)}{.81} \times 10^3 =$

$= 56,500$ psi

SUBJECT S.S.R.M - Retainer Piston

BY H. EFRON   CHK. BY   DATE

$$F_b = F_{tu} + 80{,}000$$

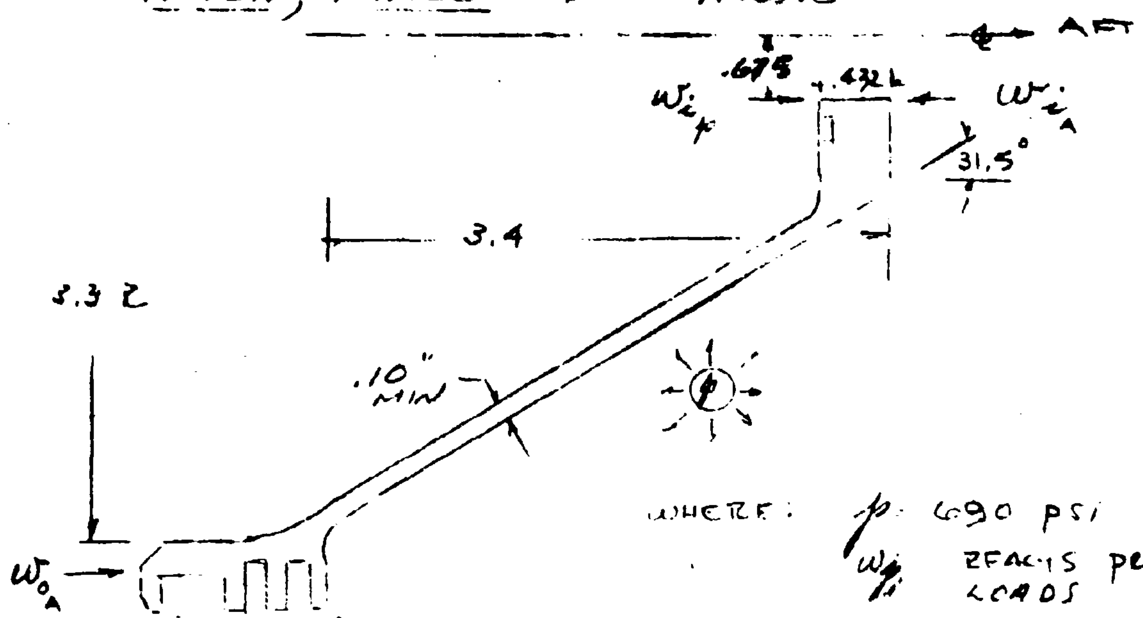
$$= 180{,}000 + 80{,}000 = 260{,}000 \text{ psi}$$

$$M.S. = \frac{260.0}{57.0} - 1 = \underline{\underline{Hi}}$$

AEROJET-GENERAL CORPORATION SACRAMENTO • CALIFORNIA

	REPORT NO.	PAGE 15 OF
SUBJECT SEC 3.1.5 SSRM - PISTON, PINTLE		DATE
		WORK ORDER
BY H. EFRON	CHK. BY	DATE

PISTON, PINTLE DWG 1146583



WHERE: p = 690 psi

W_{i_p} = REACTS PRESSURE (p) LOADS

W_{i_A} + W_o = REACT ACTUATOR LOADS

FIG 3.1.5.1

CONE

Hoop Stress:

$$f_H = -\frac{pR}{t\cos 31.5^\circ} = -\frac{690(3.4)}{.1(.853)} = -27000 \text{ psi}$$

$F = 160,000$ psi

$$M.S. = \frac{160}{27} - 1 = Hi$$

AEROJET-GENERAL CORPORATION
SACRAMENTO · CALIFORNIA
ABCD-0000-11
REPORT NO.

SUBJECT: SSRM - Piston, Pintle

BY: H. EFRON CHK. BY: DATE:

ELASTIC STABILITY REF (1) SHELL STRENGTH
W. L. VAUGHAN
DESIGN NEWS 3/28/63
(2) FIG 3.1.5.1 p 3.1.5.1

$$\frac{D}{L} = \frac{6.8}{3.4} = 2.0$$

$$\frac{t}{D} = \frac{.1}{6.8} = .0147$$

$$P_{CR} = EK$$

$$E = 30 \times 10^6$$

$$K = .00009 = 9 \times 10^{-5}$$

$$= 30 \times 9 \times 10^1 = 2700\ psi$$

$$p = 690\ psi$$

$$M.S. = \frac{P_{CR}}{p} - 1 = \frac{2700}{690} - 1 = \underline{\underline{H}}$$

RING 1 REF p 3.1.5.1
ASSUME ① ONLY PRESSURE LOADS ACTING
" ② RING RESISTS THE ENTIRE PRESSURE LOADING IN RING ROTATION

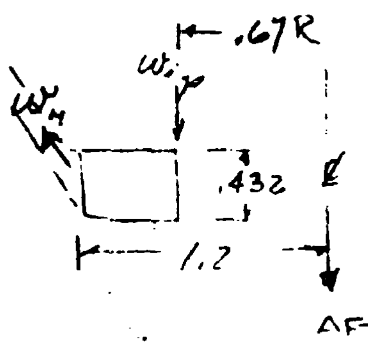


FIG 3.1.5.2

$$I = \frac{.53 \times .432^3}{12} = 3.5 \times 10^{-3}\ IN^4$$

$$A = .432 \times .57 = .25\ IN^2$$

AEROJET-GENERAL CORPORATION SACRAMENTO · CALIFORNIA

A869-0000-11

REPORT NO.

PAGE

SUBJECT SSRM - PISTON PINTLE

DATE

WORK ORDER

BY H. EFRON

CHK. BY

DATE

BENDING STRESS

$f_b = \frac{M_c R}{I}$

$I = 3.5 \times 10^{-3}\ IN^4$ REF FIG 3.1.5.1

$c = .216\ IN$

$R = .93\ IN$

$M = .6 \frac{P_{Ej_p}}{2\pi R} = \frac{.3\, P_{Ej_p}}{\pi R}$

$= \frac{.3\, P_{Ej_p}(.216)}{\pi\, 3.5 \times 10^{-3}} = \frac{.016}{\pi} P_{Ej_p} \times 10^3$

$P_{Ej_p} = 11000\ \#$ REF p 3.1.1.1

$= 16.0\ (11000) = 183{,}000\ psi$

$F_b = 180{,}000 + 80{,}000 = 260{,}000\ psi$

$R_b = \frac{f_b}{F_b} = \frac{183{,}000}{260{,}000} = .706$

HOOP TENSION

$f_H = \frac{WR}{A}$

$W = \frac{P_{Ej_p}}{2\pi R} \text{ TAN } 31.5^\circ$

$= \frac{11000(.6128)}{2R} = \frac{3370}{R}$

$= \frac{3370}{.25} = 13500\ psi$

$F_T = 180{,}000\ psi$

$R_T = \frac{13500}{180{,}000} = .075$

COMBINED STRESS

$\Sigma R = R_B + R_T = .675 + .075 = .75$

$M.S. = \frac{1.0}{.746} - 1 = \underline{.33}$

SUBJECT SEC 3.1.6

BY H. EFRON
CHK. BY
DATE

HOUSING, PINTLE #1146995

4130 STL
H.T. 150 KSI, MIN YLD

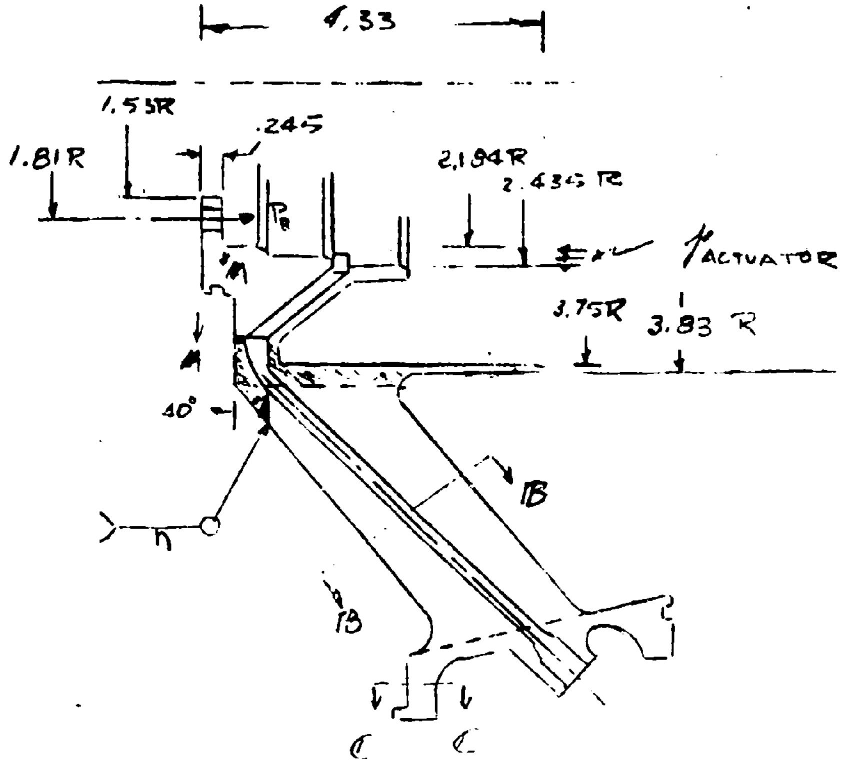


Fig 3.1.6.1

@ SEC 1A-1A WHERE $t = .245''$

THE BOLTS HOLDING THE PISTON TO THE HOUSING ARE LOADED BY THE ACTUATOR PRESSURE ACTING OVER $2.194 < R < 2.435$.

$P = p_{ACT}\,\pi(2.435^2 - 2.194^2)$ REF. FIG 3.1.6.1

$= 3750\,\pi(5.985 - 4.855) = 1.13\,\pi(3750)$

$= 4250\,\pi$ #

BENDING STRESS

$f_b = \frac{6M}{t^2}$

$M = (2.194 - 1.81)\frac{P}{2\pi\ldots 2} = \frac{.374\ (4250)}{4.368}$

$= 365$ in-#/in

$t = .245''$

$= \frac{6(365)}{(.245)^2}$ 36,500 PSI

$F_b = 150\,000$ PSI

M.S. $= \frac{150.0}{36.5} - 1 =$ Hi

SHEAR STRESS

$f_s = \frac{3}{2}\frac{P}{A} =$

$A = 2\pi R t = 2\pi\ 2.194(.245) = 1.09\pi$

$= \frac{4250}{1.09} \times 1.5 = 3900 \times 1.5 = 5950$ PSI

$F_s = 90{,}000$ PSI

M.S. $= \frac{90.0}{5.95} - 1 =$ Hi

BOLTS - PISTON TO HOUSING 1/4 - 28 SOCKET HEAD -- 10 REQ'D

$P_b = \frac{P}{10} = \frac{4250\pi}{10} = 1330$ #/BOLT

$P_{ALL} = 6900$ #/BOLT

M.S. $= \frac{6900}{1330} - 1 = 4.1$

RING - RADIAL KICK LOADS P_R

— ℄ — AFT

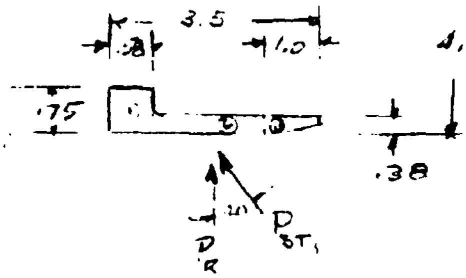


FIG 3.1.6.2

EVALUATING P_R (NEGLECTING AFT ACTING PRESSURE ON PINTLE)

$$P_R = P_{ST} \cos 40°$$

$$= \frac{p \pi r^2}{3 \sin 40°} \cos 40° = \frac{p}{3} \pi r^2 \cot 40°$$

WHERE p = 690 PSI
* r = 4.6" SEE FIG

$$= \frac{690 \pi}{3} 4.6^2 (1.19) = 18{,}000 \text{ \#/STRUT}$$

EVALUATING GEOMETRY OF THE RING

ITEM	AREA	Y	AY	AY²	I₀
1	.435	.375	.163	.062	.0206
2	.730	.19	.138	.026	.0089
3	.195	.25	.050	.012	.0020
Σ	1.360		.351	.100	.0315

$$I_{xx} = \Sigma I_0 + \Sigma A y^2 - \Sigma A \bar{y}^2 \qquad \bar{y} = \frac{\Sigma A y}{\Sigma A} = \frac{.351}{1.36} = .260$$

$$= .0315 + .100 - (1.36)(.260)^2 = .039 \text{ in}^4$$

$\Sigma A = 1.36 \text{ in}^2$

$c = .75 - .26 = .49$ in

$R_{cg} = 3.97"$

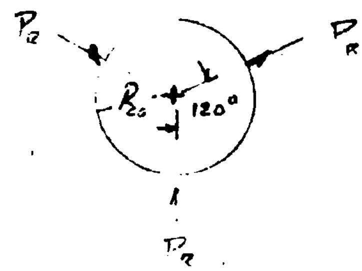
* INCREASE OF ... RADIUS SEE 3.75"

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA
AGC8-8800-11

SUBJECT 55" RM-20 PULSE	REPORT NO.	PAGE III.6.4
		DATE 3/12/68
		WORK ORDER
BY H. EFRON	CHK. BY	DATE

EVALUATING BENDING STRESS, f_b

$f_b = \frac{Mc}{I} K_b$



$R_{cc} = 3.97$

FIG 3.1.6.3

$M = .5 P_R R_{cc} \left(\frac{1}{\theta} - \cot\theta\right)$ REF. ROARK TABLE VIII CASE 9 FORMULAS FOR STRESS & STRAIN

$P_R = 18{,}000^{\#}$

$\theta = \pi/3 = 1.05$

$\cot\theta = 1.732$

$= .5(18000)(3.97)(.777) = 27{,}000$ "-#

$K_b < .50$ FACTOR TO ALLOW FOR THE STIFFNESS CONTRIBUTED TO THE RING BY
1. CYLINDER AFT OF THE RING
2. BOSS ON THE SEALING PISTON OF THE PINTLE.

$f_b = \frac{27{,}000\,(.49)(.50)}{.039} = 173{,}000$ psi

$F_{ty} = 150{,}000$ psi

$F_b = 1.25\, F_{ty} = 188{,}000$ BENDING MODULUS

$M.S._b = \frac{188}{173} - 1 = +.09$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0000-11

REPORT NO.

PAGE

DATE 8/17/68

WORK ORDER

SUBJECT SSRM

BY H. EFRON CHK BY DATE

EVALUATING COMPRESSIVE STRESS @ X-SECTION

$f_c = \frac{P_R}{A} K_T$

WHERE $K_T = .5 \cot 60° = .87$

$P_R = 18,000^{\#}$

$A = 1.36 \text{ in}^2$

$= \frac{18,000 (.87)}{1.36}$

$= 11,500$ psi

$F_y = 150,000$ psi

$M.S. = \frac{150}{11.5} - 1 = \underline{Hi}$

COMBINED STRESS: COMP. + BENDING

$R = R_T + R_B$ STRESS RATIO

$R_T = \frac{f_T}{F_T} = \frac{11,500}{150,000} = .076$

$R_B = \frac{f_b}{F_b} = \frac{173,000}{189,000} = .92$

$R = .996$

$M.S. = \frac{1}{R} - 1 = \frac{1}{.996} - 1 = \underline{\underline{+0.0}}$

DEFLECTION, RADIAL ΔR - REF: ROARK: TABLE VIII CASE 5 FORMULAS FOR STRESS & STRAIN

$\Delta R = \frac{WR^3}{2EI}\left[\frac{1}{2\sin^2\theta}\left(\theta + \sin\theta\cos\theta\right) - \frac{1}{\theta}\right]$

$\theta = \pi/3 = 1.050$ RAD

$W = 18,000^{\#}$ DESIGN LOAD

$R^3 = R_{CL}^3 = 3.97^3 = 62$

$EI = 30 \times .039 \times 10^6 = 120 \times 10^4$

$\Delta R = \frac{18,000 \times 62}{240 \times 10^4} \times .035 = .016''$ @ DESIGN LOAD

$.012''$ @ LIMIT LOAD

BASED ON R = 3.75'' FOR DEFLECTING LOADS

$\Delta R = .012 \times \frac{3.75^2}{...} = .008''$ @ ACTUAL LOAD

AEROJET-GENERAL CORPORATION SACRAMENTO • CALIFORNIA

AGC8-0000-11

REPORT NO.	PAGE 71.6.10
SUBJECT SS RM - 20 PULSE	DATE 5/12/68
	WORK ORDER
BY H. EFRON	CHK. BY	DATE

ELASTIC STABILITY OF THE CYLINDER

REF: SHELL STRENGTH - VAUGHN
DESIGN NEWS 3/20/63

$P_{cr} = KE$

EVALUATING K

$\frac{D}{L} = \frac{7.623}{4.33} = 1.78$ REF: FIG 3.1.61

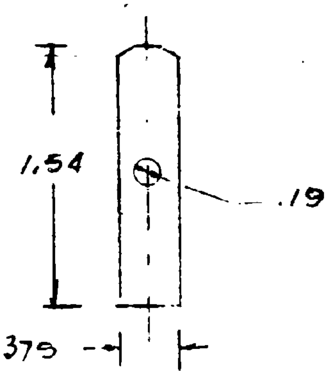
$\frac{t}{D} = \frac{.08}{7.6} = .0105$

$\therefore K = 6 \times 10^{-5}$

$= 6 \times 10^{-5} \times 30 \times 10^{6} = 1.80 \times 10^{3}$

$M.S. = \frac{1.8 \times 10^3}{630} - 1 = H.$

@ SEC B-B - STRUT



$A = .375 \times 1.5 - \pi(.095)^2 =$
$= .563 - .03 = .533\ IN^2$

$I \cong \frac{bh^3}{12}$
$\cong \frac{1.5}{12}(.375)^3 = \frac{1.5}{12}(.054) =$
$\cong .00675\ IN^4$

$\rho = \sqrt{\frac{I}{A}} = 10^{-1}\sqrt{\frac{.675}{.533}} = 0.112$

FIG 3.16.4

$l = 4.5''$ LENGTH OF COLUMN

COMPRESSIVE STRESS:

$f_c = \frac{P_T}{A} = \frac{690\pi(4.6)^2}{3 \sin 40^\circ (.533)} = 44{,}500$ PSI

EULER ALLOWABLE - PINNED COLUMN

$F_c = \frac{\pi^2 E}{\left(\frac{l}{\rho}\right)^2} = \frac{30 \times 10^6 \times 9.9}{\left(\frac{4.5}{.112}\right)^2} = 182{,}000$ PSI

$M.S. = \frac{150{,}000}{44{,}500} - 1 = H.$

BEAM COLUMN

ASSUME THAT THE STRUT IS LOADED UNIFORMLY BY A $\Delta p = 1610$ psi AS SHOWN BELOW

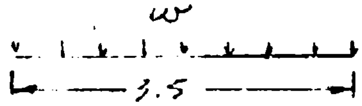


FIG 3.1.6.4

THE LOAD w IS DETERMINED FROM THE FOLLOWING NET X-SECTIONAL PROJECTED AREA:

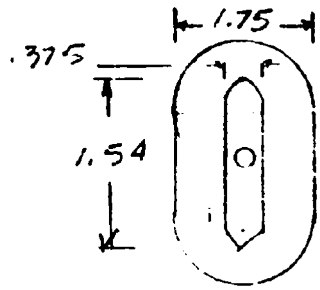


FIG 3.1.6.5

$w = 1.75\ \Delta p$
$= 1.75\,(1610) = 2820\ \#/\text{in}$

BENDING STRESS

$f_b = \dfrac{Mc}{I}$

$M = \dfrac{w\ell^2}{8} = \dfrac{2820\,(3.5)^2}{8} = 4320$ in-#

$c = .77$ in

$I = \dfrac{.375 \times 1.54^3}{12} = .115\ \text{in}^4$

$= \dfrac{4320\,(.77)}{.115} = 29000$ psi

COMBINED STRESS

$\Sigma f = f_c + f_b$

$f_c = 44{,}500$ psi, SEE p. 3.1.6.6

$= 44{,}500 + 29{,}000 = 73{,}500$ psi

$F_c = 150{,}000$ psi

$M.S. = \dfrac{150.0}{73.5} - 1 = \underline{\underline{H_i}}$

STRESS DUE TO ACTUATOR FLUID PRESSURE IN THE .190" DIA. HOLE

$f_H \approx \frac{pR}{t}$ REF: FIG 3.1.6.4

$= \frac{3750(.095)}{.5(.375-.19)} = 3850$ psi

$F_t = 150{,}000$ psi

M.S. $= \frac{150.0}{3.85} - 1 = H.$

EXTERNAL SHELL:

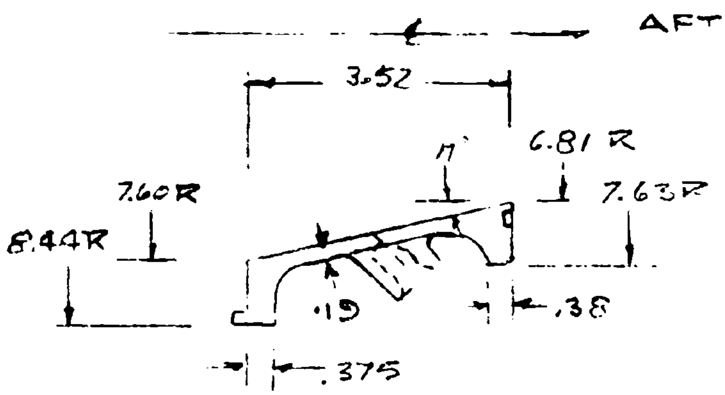


FIG 3.16.6

THE SHELL RESISTS:

1. INTERNAL PRESSURE $p = 690$ psi
2. STRUT LOADS $P_R = 18000$ #

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0000-11

SUBJECT		REPORT NO.	PAGE
SSRM-20 PULSE			DATE 9/13/68
BY N. EFRON	CHK. BY		DATE

HOOP STRESS DUE TO $p = 690$ psi

$$f_H = \frac{pR}{t\,\eta_{05}} \qquad .0051\,7$$

$$= \frac{690\,(7.6)}{.19\,(.95)} = 29{,}000 \text{ psi}$$

$$F_{ty} = 150{,}000 \text{ psi}$$

$$M.S. = \frac{150.0}{29.0} - 1 = \underline{\underline{Hi}}$$

STRUT LOADS: P_{ST}

ASSUMPTIONS:

1. P_{ST} ⊥ TO SHELL
2. SHELL + FLANGES ACT AS ONE UNIT

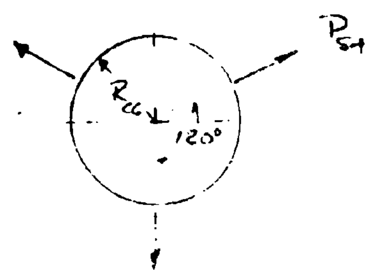


FIG 3.1.6.7

EVALUATING P_{ST} REF FIG 3.1.6.1

$$P_{ST} = \frac{p\pi r^2}{3\sin 40^\circ} = \frac{690\pi\,4.6^2}{3\,(.642)} = 23{,}500^{\#}$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA
REPORT NO.
PAGE 16
DATE 7/13/68
WORK ORDER
DATE
CHK. BY

SUBJECT: SSRM- 20 PULSE

BY: H. EFRON

EVALUATING RING GEOMETRY

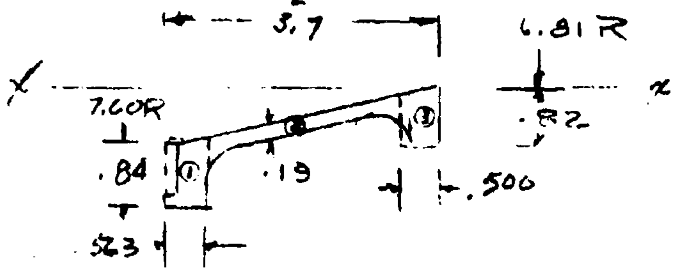


FIG 3.1.6.8

ITEM	AREA	Y	AY	AY^2	I_o
1	.473	.41	.194	.080	.0282
2	.38	.50	.190	.095	.0016
3	.41	1.21	.495	.600	.0230
Σ	1.263		.879	.775	.0528

$$I = \Sigma I_o + \Sigma A y^2 - \Sigma A \bar{y}^2$$

$$\bar{y}^2 = \left[\frac{\Sigma A y}{\Sigma A}\right]^2 = \left[\frac{.879}{1.263}\right]^2 = .7^2 = .49$$

$$= .0528 + .775 - 1.263\,(.49) = .157 \quad IN^4$$

$A = 1.263 \quad IN^2$

$R_{cG} = 6.81 + .70 = 7.51 \quad IN.$

EVALUATING BENDING STRESS:

$$f_b = \frac{Mc}{I} K$$

$M = .5 P_R R_{cG}\left(\frac{1}{\theta} - \cot\theta\right)$ REF ROARK, 3RD ED. TABLE VIII, CASE 9

$\theta = \pi/3$

$\cot\theta = 1.732$

$= .5(18000)(7.51)(.78) = 52{,}500$ "-#

$c = 8.44 - 6.81 - .7 = .93$

$K = .5$ STIFFNESS ADDED TO RINGS BY
1. LINERS
2. BOSSES & ADJACENT SHELL STRUCTURES

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA
AGCS-0800-11
REPORT NO.
PAGE
SUBJECT SSRM - 20 PULSE
DATE 8/13/60
WORK ORDER
BY H. EFRON
CHK. BY
DATE

$f_b = \frac{Mc}{I} K$

$= 52,500 \frac{(.93)}{.197} .5 = 126,000$ psi

$F_{ty} = 150,000$ psi

$M.S. = \frac{150}{126} - 1 = \underline{.19}$

EVALUATING DIRECT STRESS:

$f_T = \frac{P_{ST}}{A} K_T$

$P_{ST} = 18000^{\#}$ REF ¶ 3.1.6.3

$K_{ST} = .5607 G$ REF. ROARK TABLE VII CASE 9 FORMULAS FOR STRESS AND STRAIN

$= .866$

$= \frac{18000(.866)}{1.263} = 12,400$ psi

$F_{ty} = 150,000$ psi

$M.S. = \frac{150}{12.4} - 1 = Hi$

COMBINED STRESS:

$\Sigma f = f_T + f_B$

$= 12,400 + 126,000 = 138,400$ psi

$F_{ty} = 150,000$ psi

$M.S. = \frac{150.0}{138.4} - 1 = \underline{.08}$

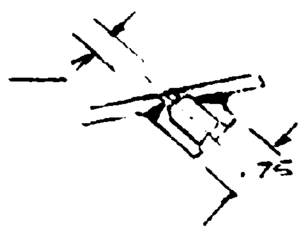
AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGC-8(70-11)

SUBJECT: SSRM 2.0 PULSE	REPORT NO.	PAGE III.1.6.12 OF
		DATE 9/13/68
		WORK ORDER
BY: H. EFRON	CHK. BY	DATE

WELDS - 100% PENETRATION REQ'D

FIG 3.1.6.9



@ PRESSURE TAPS

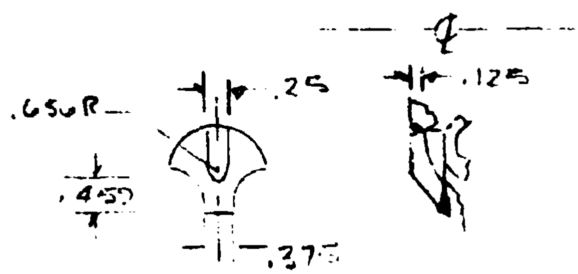
HOOP STRESS

$$f_H = p_A \frac{R}{t} = \frac{3750(.375)}{.15} = 9450 \text{ psi}$$

$F_{ty} = 150,000$ psi

M.S. = Hi

FIG 3.1.6.10



@ STRUT TO RING

BLOW-OFF LOAD P_B

$$P_B < p_A .5\pi .656^2 = 3750(.435)1.57 = 2570$$

WELD AREA A (ASSUME 1/8 WELD)

$$A > .125\,\pi\,1.3 = .51 \text{ in}^2$$

WELD STRESS

$$f_s = \frac{P_B}{A} = \frac{2750}{.51} = 5500 \text{ psi}$$

$F_{ty} = 150,000$ psi

$$M.S. = \frac{150}{5.5} - 1 = Hi$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0600-11

SUBJECT	REPORT NO.	PAGE OF
SSRM		DATE
		WORK ORDER
BY H. EFRON	CHK. BY	DATE

BOLT LOADS - HOUSING TO CHAMBER

BLOW-OFF LOAD/BOLT

$$P_B = \frac{p \pi r^2}{60} = \frac{690 \pi 7.6^2}{60} = 2100^{\#}/\text{BOLT}$$

KICK LOAD

$$P_K = P_B \times \frac{9.0 - 7.6}{9.3 - 9.0} = \frac{.4}{.3} P_B = 1.33 P_B$$

TOTAL LOAD/BOLT

$$\Sigma P = 2.33 P_B = 2.33 (2100) = 4900^{\#}$$

$\frac{1}{4}$ - 28 BOLTS → $6900^{\#}$ ALLEN HEX-HD

$$M.S. = \frac{6900}{4900} - 1 = \underline{\underline{.40}}$$

@ SEC C-C

BENDING:

$$f_b = \frac{6M}{Kt^2}$$

$t = .375$

$$M = \frac{pR}{2} (9.00 - 7.7)$$

$$= (69)(7.7)(\frac{.3}{2}) = 800 \text{ ''-\#/in}$$

$$K = \frac{\pi D - 6.0(.28)}{\pi D} = \frac{50 - 17}{50} = .68$$

$$= \frac{6(800)}{(.141)(.69)} = 50000 \text{ PSI}$$

$F_{ty} = 150,000$ PSI

$$M.S. = \frac{150}{50} - 1 = \underline{\underline{Hi}}$$

AEROJET-GENERAL CORPORATION SACRAMENTO • CALIFORNIA

AGC8-0800-11

REPORT NO.	III. 1.7-1 PAGE OF

SUBJECT: SSRM ENTRANCE CAP DWG # 1147005

DATE

WO / ORDER

BY: W. JORDAN | CHK. BY | DATE

MATERIAL 4130 STEEL

F_{tu} = 90 KSI

F_{ty} = 70 KSI

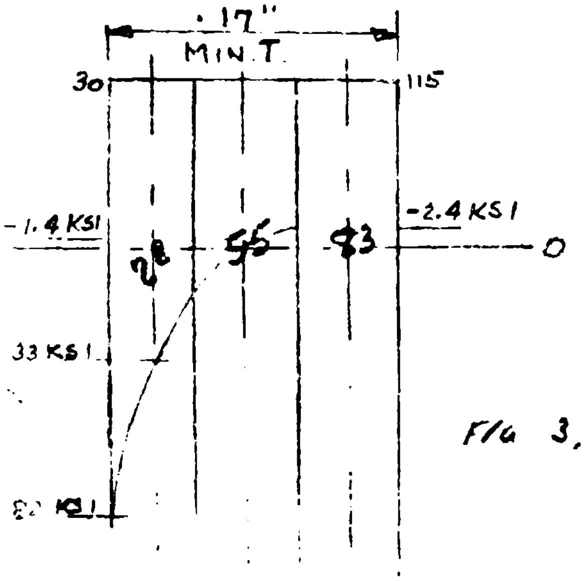
PRESSURE 1.25 x 550 PSI = 690 PSI

THE CAP WAS ANALYZED MAKING USE OF THE FINITE ELEMENT COMPUTER PROGRAM E 11401 (REF. AGC STRUCTURES MANUAL)

THE FINITE ELEMENT GRID IS SHOWN ON PAGE 3.1.1.2 THE NODAL POINTS 1, 9, 17, 25, 52, 80 & 109 BEING FIXED IN R & Z DIRECTION. NODAL POINTS 171 & 174 BEING PERMITTED TO ROLL OR SLIDE IN RADIAL DIRECTION AND RESTRAINED IN Z DIRECTION.

AS EXPECTED THE HIGHEST STRESSES OCCURED ACCROSS ELEMENTS 28, 55 & 83 NEAR THE CENTER OF THE CAP.

THE FINITE ELEMENT PROGRAM COMPUTES STRESSES AT THE CENTER OF EACH ELEMENT, WHEN BENDING IS PRESENT THESE STRESSES SHOULD BE EXTRAPOLATED TO THE OUTSIDE SURFACE OF THE CAP TO DETERMINE THE MAX. STRESS.



MAX SKIN STRESS = 80 KSI

$$M.S. = \frac{70 \times 1.25^{*}}{80} - 1 = +.09$$

*NOTE :- 1.25 BENDING MODULUS

FIG 3.1.7.1

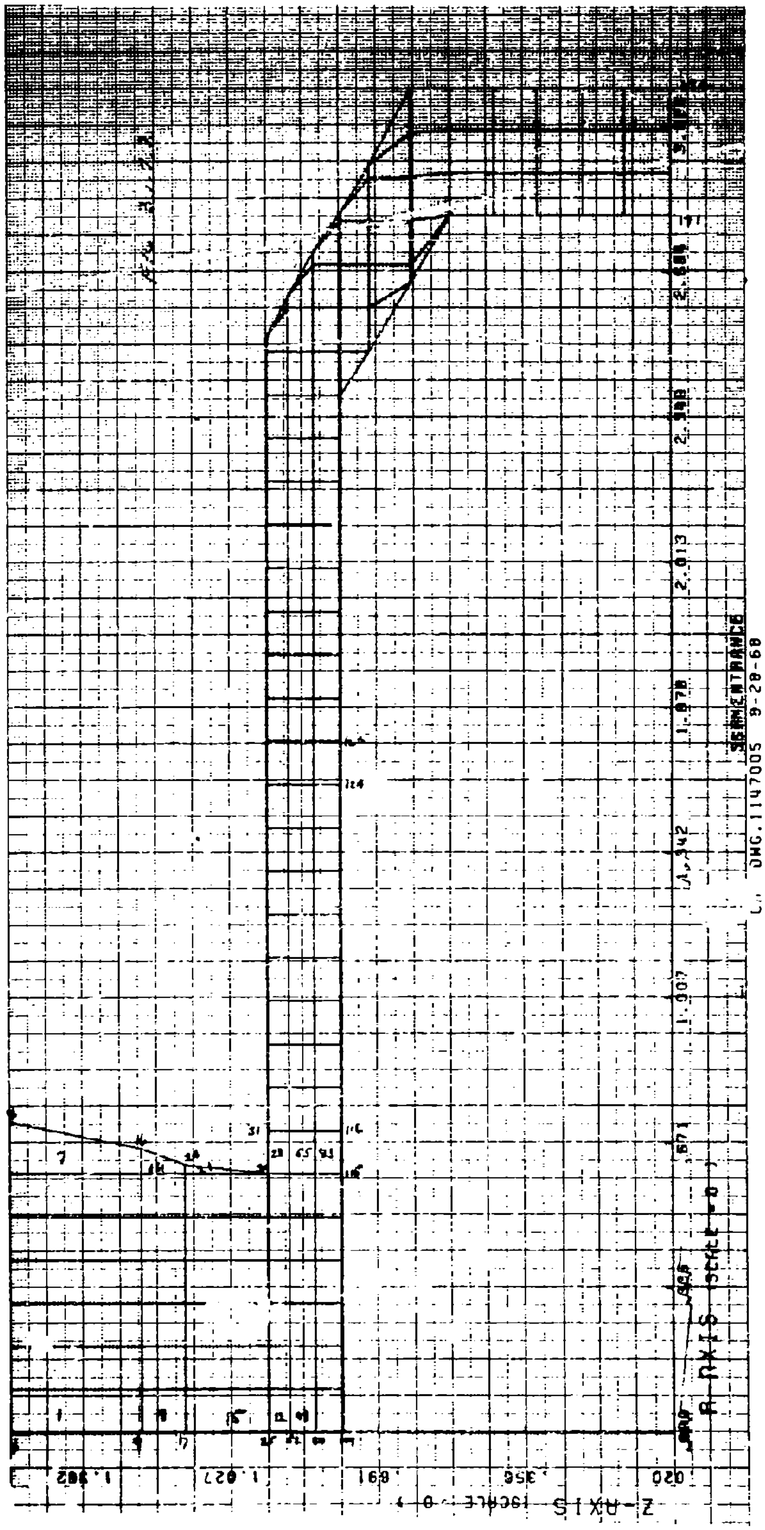
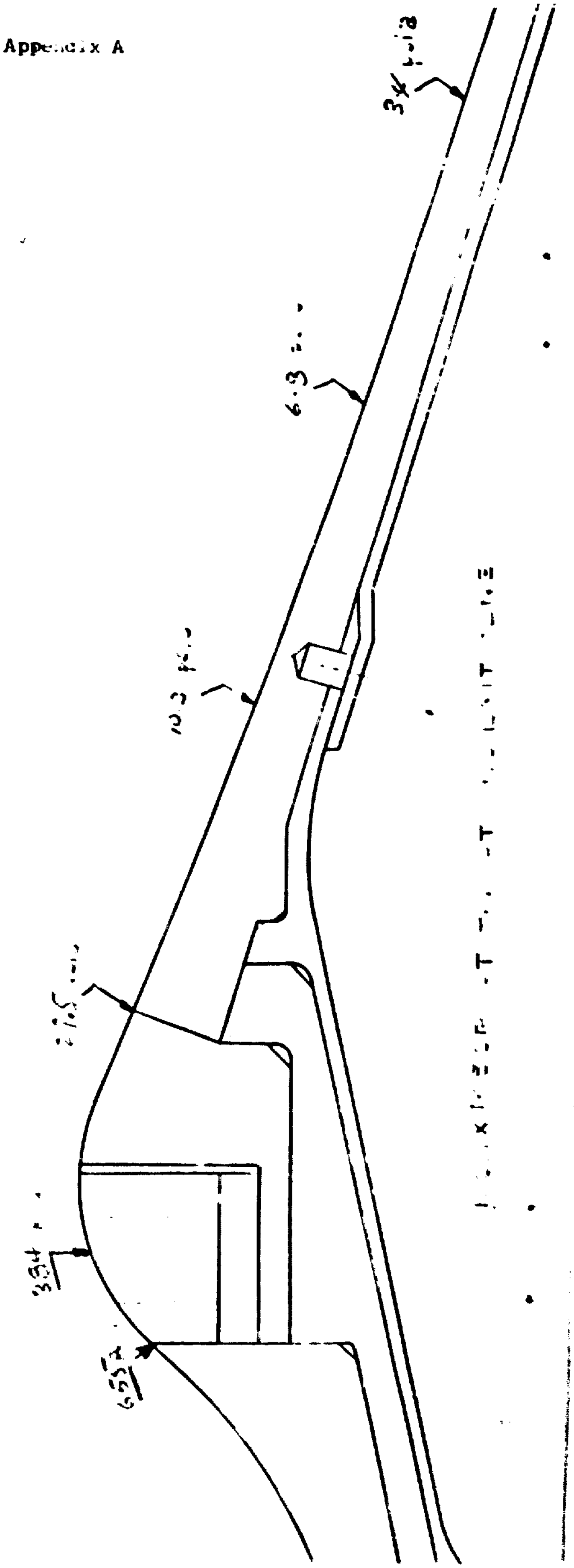


Figure 3.1.7.2

FIG 3.1.8.0

ESTIMATED PRESSURES FOR
DESIGN YIELD IGNITION [illegible]



SUBJECT	REPORT NO.	PAGE
SSRM EXIT CONE PIN DWG # 1147016		
BY W. JORDAN	CHK. BY	DATE

MATERIAL SILICA PHENOLIC (MX 2646) AGC 34312-1

F_{su} = 5500 PSI
F_t = 27,000 PSI
REF FIBERITE HANDBOOK MARCH 1, 1963 (H. EFRAN)

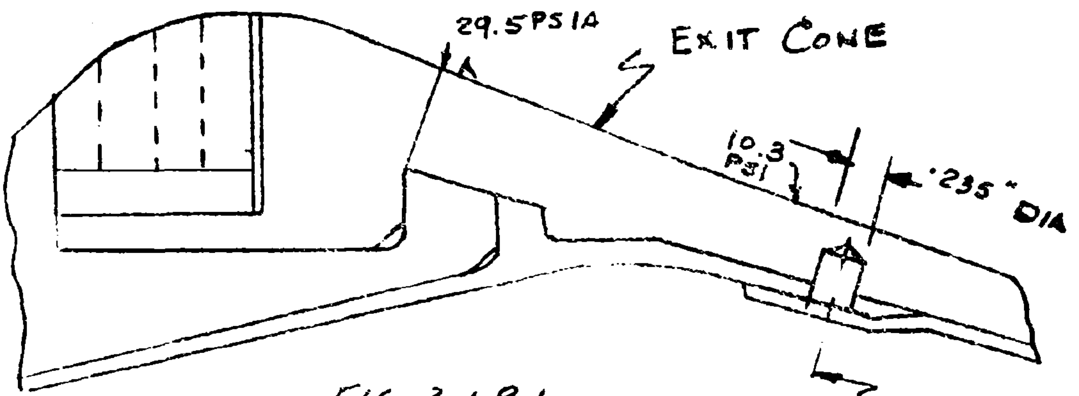


FIG 3.1.8.1

LOAD ON PINS

ASSUME PRESSURE (29.5 PSI) HAS ACCESS BEHIND EXIT CONE AT POINT A

THEN POSSIBLE SHEAR LOAD ON PIN

$$= \frac{29.5 \times \pi (5.92^2 - 4.22^2) - \left(\frac{29.5 + 10.3}{2}\right)\pi(5.53^2 - 4.22^2)}{6}$$

$$= \frac{1597.6 - 812.4}{6} = 131\ \#/\text{PIN}$$

$$\sigma = \frac{P}{A} = \frac{131}{.7854 \times ((.225)^2 - (.07)^2)} = 3649$$

$$M.S. = \frac{5500}{3649} - 1 = +.51$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0000-11

SUBJECT	REPORT NO.	PAGE OF
SSRM SHELL NOZZLE DWG 1147008		DATE 8-28-68
		WORK ORDER
BY W. JORDAN	CHK. BY	DATE

MATERIAL STEEL TYPE 4130 MIL-S-6758 COND C3.

$F_{ty} = 150{,}000$ PSI

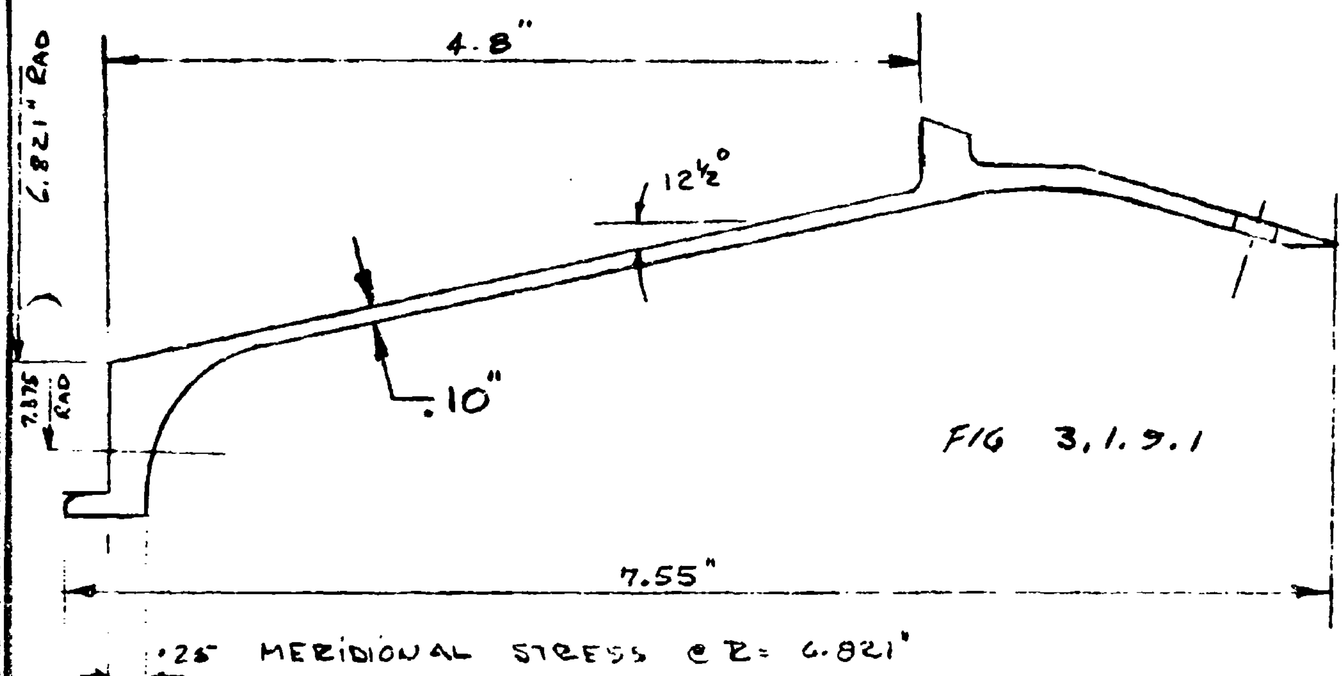


FIG 3,1.9.1

MERIDIONAL STRESS @ R = 6.821"

$$\sigma_M = \frac{PR}{t \cos\theta} = \frac{690 \times 6.821}{.09 \times .97630} = 53{,}564 \text{ PSI}$$

M.S. = HIGH.

$$\epsilon = \frac{53564}{29 \times 10^6} = .0018"$$

SUBJECT

DATE

WORK ORDER

BY

CHK. BY

DATE

NOZZLE SHELL CONT.

BOLT LOAD 74,590 × 1.30

$$\text{BOLT LOAD/INCH} = \frac{74,590 \times 1.30}{2 \times \pi \times 7.1} = 2174^{\#}$$

$$\sigma = \frac{6M}{t^2} = \frac{6 \times 2174 \times .55}{(.25)^2} = \underline{114,787 \text{ PSI}}$$

$$\sigma_A = \frac{2174}{.25} = 8,696 \text{ PSI}$$

$$\text{M.S} = \frac{150000}{114787} - 1 = +\underline{.31}$$

LIP ON NOZZLE SHELL

$t = .295$

$$\text{LOAD} = \frac{690\,\pi\,(5.8^2 - 4^2)}{2\,\pi \times 5.326} = 1143^{\#}$$

$$\sigma = \frac{1143}{.295} + \frac{6 \times 1143 \times .285}{(.295)^2}$$

$$= 3875 + 22459 = 26334 \text{ PSI}$$

M.S. HIGH.

NOZZLE SHELL CONT.

BOLT LOAD $= P\pi\{a^2 - b^2\}$

WHERE a = SEAL RADIUS = 7.1"

b = 4" (THROAT PINTLE SEE PG 3.1.1.1

P = 690 PSI

BOLT LOAD $= 690 \times \pi\{(7.1)^2 - 4^2\}$

$= 74,590$#

30 - 1/4" DIA BOLTS

LOAD/BOLT $= \frac{74590}{30} = 2486$# DIRECT LOAD

ASSUME 30% DIRECT LOAD FOR BENDING

LOAD/BOLT $= 1.3 \times 2486 = 3232$#

1/4" BOLT 28 TPI

TORQUE 50-80 IN-LBS

LOAD IN BOLT @ MIN TORQUE

$P_{b1} = \frac{T}{R} A.$ $A = .0326$ IN^2
$R = .00087$ (LUB).

$\frac{80 \times .0326}{.00087} = 2998$# FOR $F_{tu} = 160$ KSI BOLT.

PITCH OF BOLTS = 1.49"

USE HIGH STRENGTH BOLTS WITH SUITABLE TORQUE

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0800-11

REPORT NO.

PAGE OF

DATE 8-29-68

WORK ORDER

SUBJECT

SS RM SHELL NOZZLE THROAT DWG 1147012

BY W. JORDAN

CHK. BY

DATE

MATERIAL PYROLYTIC GRAPHITE

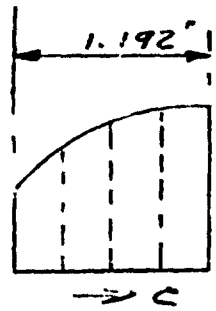


FIG 3.1.10.1

TEMP 5000° F @ INSIDE SURFACE

COEF. OF THERMAL EXP α = 120×10⁻⁶ IN/IN/°F REF AGC MAT^L DATA SHEETS

$\Delta = \alpha \Delta t L$

$= 12.0 \times 10^{-6} \times (5000-70) \times 1.192$

$= .07[illegible]519''$

NOTE THE ACTUAL EXPANSION OF GRAPHITE [illegible] IT CONTACTS THE RUBBER WASHER DWG NUMBER 114[illegible] DURING FIRING IS ABOUT 50% OF [illegible] ABOVE. (ie ABOUT .035").

RUBBER WASHER DWG # 1147011-1

MATERIAL (V-44) AGC-34161

SHORE HARDNESS 85A

E_{comp} = 700 PSI

t = .060

$\sigma_{comp} = 700 \times \frac{1}{.060} \times (.060 - .035) = 292$ PSI

M.S. HIGH

NOTE- INCOMPLETE; THERMAL ANALYSIS REQ'D

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0800-11

SUBJECT	REPORT NO	PAGE OF
OUTER NOZZLE ASSY. DWG^N 1147006		DATE
		WORK ORDER
BY W. JORDAN	CHK. BY	DATE

MATERIAL GLASS CLOTH STYLE NO 1583 OR EQUIVALENT

$F_b = 60.000$ PSI (WARP) } FROM AGC SOURCE

$E = 3 \times 10^6$ PSI ✓ } 9-3-68

$t = 6$ PLIES $= 6 \times .009 = .054$ (COMPOSITE)

$\theta = 16°$

$$\sigma_H = \frac{PR}{t \cos\theta} = \frac{29.5 \times 6.1}{.054 \times .96126} = 3{,}466 \text{ PSI}$$

M.S = HIGH

$$\epsilon = \frac{\sigma}{E} = \frac{3466}{3 \times 10^6} = .001155 \text{ "/INCH}$$

$.0011 < .025$ OK.

@ $P = 3.4$

$r = 7.2"$

$$\sigma_H = \frac{3.4 \times 7.2}{.054 \times .96126} = 472 \text{ PSI}$$

M.S = HIGH.

MISCELLANEOUS PARTS

PART	DWG. NO	REMARKS
THROAT APPROACH	1147014	THERMAL ANALYSIS OF THIS PART APPEARS IN SEC 3.2
SLEEVE	1147013	SAME
SUPPORT, THROAT	1147010	SAME
INSULATOR, THROAT	1147009	SAME
THROAT, NOZZLE	1147012	SAME
RING, PISTON	1147004	NON-STRUCTURAL
EXIT CONE	1147015	" "
SPACER, THROAT-NOZZLE	1147011	" "

THERMAL STRESS ANALYSIS

RESULTS OF FINITE ELEMENT COMPUTER PROGRAM E 11405

FIGURES 3.2 AND 3.2.5 SHOW THE PORTIONS OF THE PINTLE AND SHROUD EVALUATED BY THE COMPUTER USING AGC COMPUTER PROGRAM E 11405.

THE RESULTS OF THE THERMAL STRESS ANALYSIS FOR SELECTED CRITICAL AREAS ARE REPORTED IN THIS SECTION.

COMPONENT	M.S.	¶
PINTLE COUPLING	Hi	3.2.1.1
" THROAT RETAINER	0.13	3.2.2.2
PINTLE THROAT	0.00	3.2.4.1 & 2
SHROUD THROAT	.34	3.2.5.1

THIS ANALYSIS USES A F.S. = 1.0, THEREFORE, AT LIMIT LOADS

Preceding Page Blank

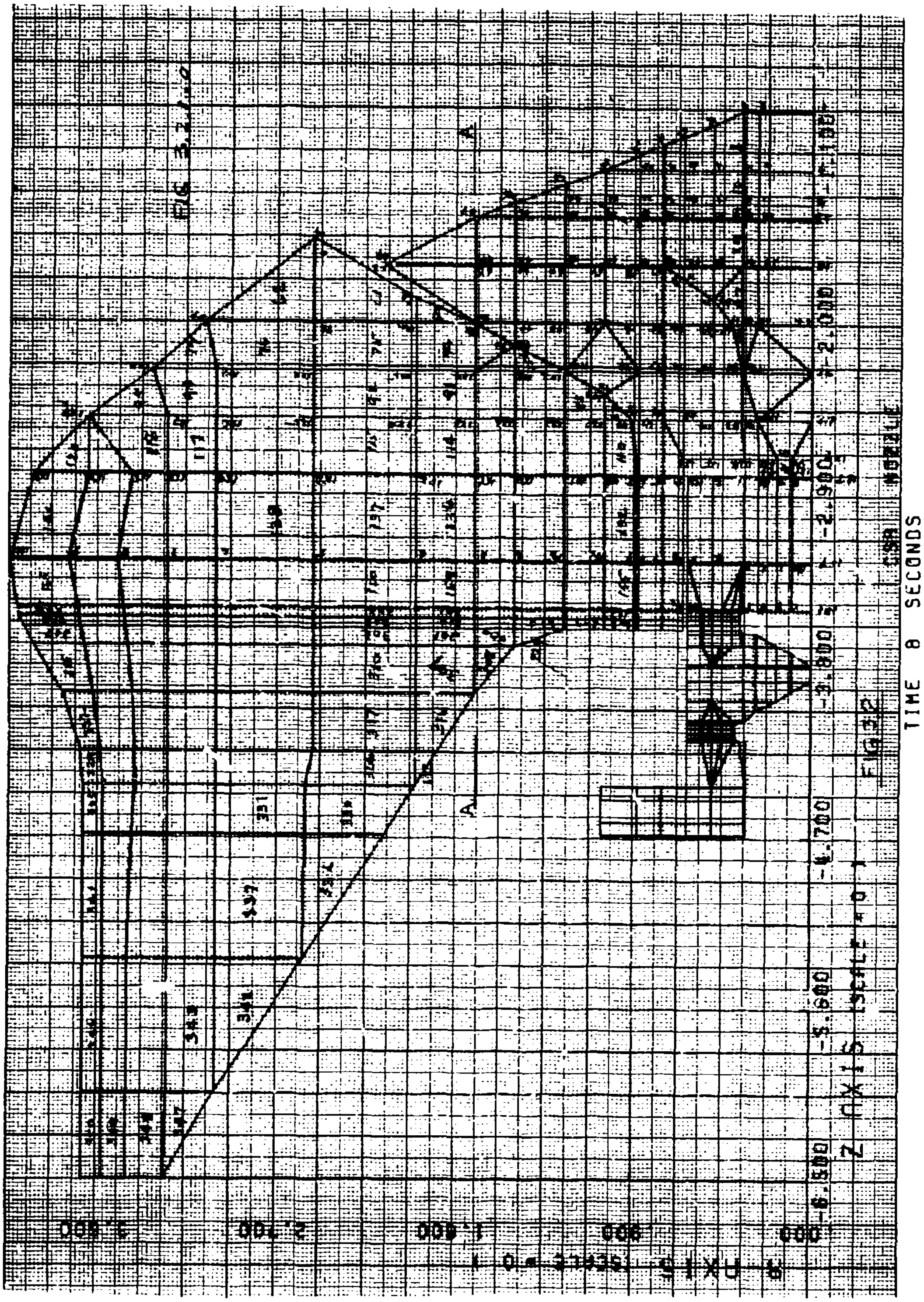
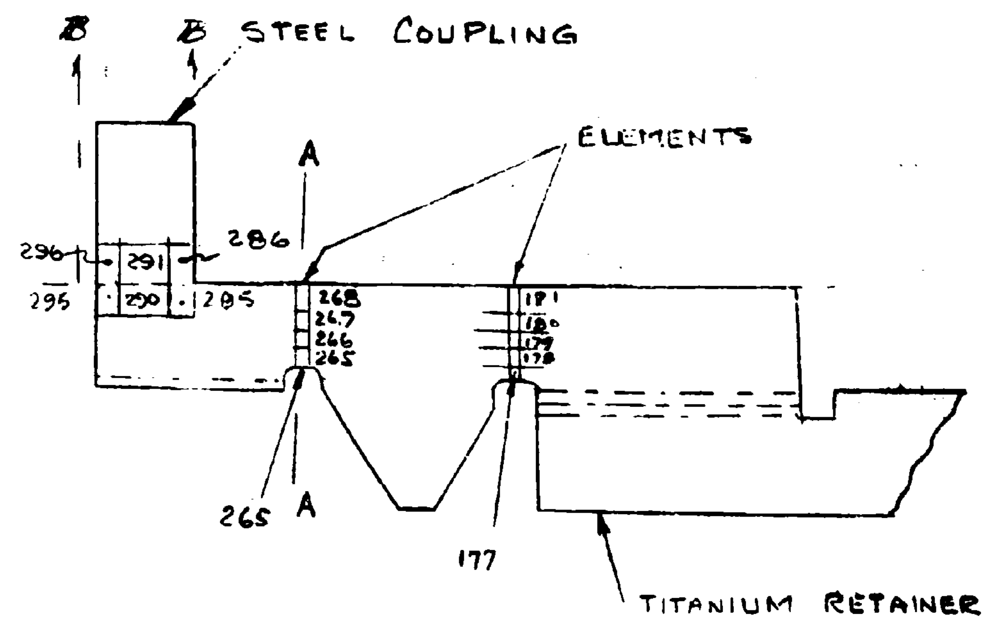


Figure 3.2.1.0

SSRM COUPLING

MATERIAL STEEL 4130

FIG 8.2.1.1



FROM COMPUTER CALCULATIONS, MAX STRESS OCCURS AT A – A

$$\text{ELEM } 265;\ 37121\ \text{PSI} \times \pi(.45^2 - .39^2) = 1871\pi$$
$$266;\ 33{,}493 \times \pi(.50^2 - .45^2) = 1591\pi$$
$$267;\ 36{,}024 \times \pi(.56^2 - .5^2) = 1991\pi$$
$$268;\ 36961 \times \pi(.625^2 - .56^2) = \underline{3257\pi}$$
$$8610\pi$$

$$\text{CROSS-SECTION AREA} = \pi(.625^2 - .39^2) = .2385\pi$$

$$\text{AVERAGE STRESS} = \frac{8610}{.2385} = 36{,}100\ \text{PSI}$$

AT B-B

ELEM 295 ; 15044 psi SHEAR STRESS

$$M.S._{A\text{-}A} = \frac{150{,}000}{36{,}100} - 1 = \underline{Hi}$$

$$M.S._{B\text{-}B} = \frac{80{,}000}{15{,}049} - 1 = \underline{Hi}$$

SUBJECT

SSRM RETAINER THROAT DWG 1147003

WORK ORDER

BY CHK BY DATE

MATERIAL: TITANIUM ALLOY (6AL-4V)

F_{ty} = 150 KSI @ ROOM TEMP.

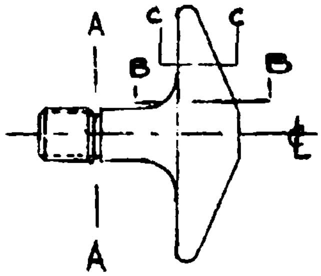


FIG 3.2.2.1

FROM COMPUTER ANALYSIS, THE HIGHEST STRESS IS AT SECTION A-A

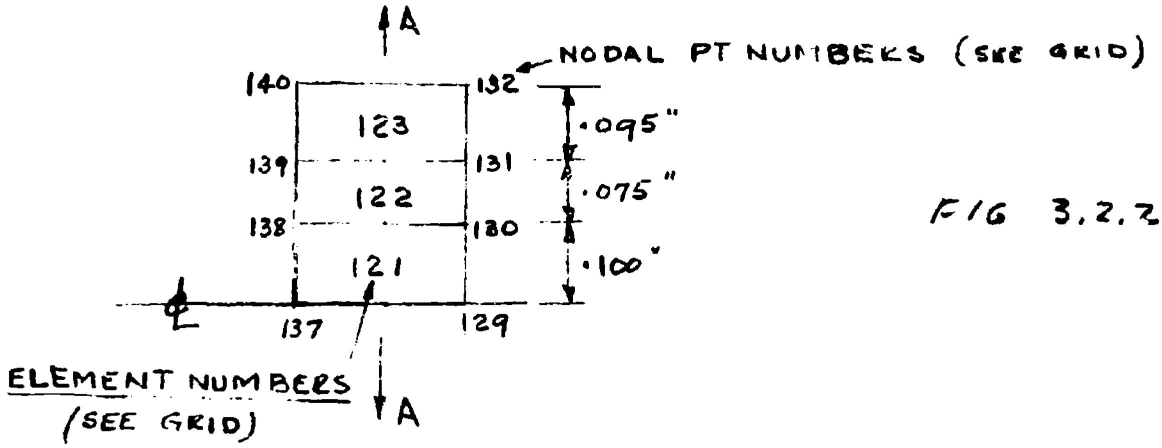


FIG 3.2.2.2

FOR TIME 8 SECONDS t = 80° F

LOAD ACROSS A-A = $151,900 \times \pi \times (27^2 - .175^2)$ = 6422 (π)
$76,495 \times \pi \times (.175^2 - .1^2)$ = 1588 (π)
$69,961 \times \pi \times (.1)^2$ = 700 (π)
8710 π

FROM DRAWING DIA. @ UNDERCUT = .562 − .01 (TOL) = .552

A = .0762 π IN^2

AVERAGE STRESS ACROSS SECTION = 114300 PSI

SUBJECT		REPORT NO. / PAGE OF / DATE / WORK ORDER
BY	CHK. BY	DATE

RETAINER THROAT CONT.

@ TIME 750 SECS TEMP = 200°F

LOAD ACROSS A-A = $151,220\ \pi (.27^2 - .175^2) = 6393\ \pi$

$77955\ \pi (.175^2 - .1^2) = 1608\ \pi$

$71030\ \pi (.1^2) = 710\ \pi$

$8711\ \pi$

$A = .0762\ \pi\ IN^2$

AVERAGE STRESS ACROSS SECTION AT A-A

$= \frac{8711}{.0762} = 114,318$ PSI @ 200°F

TEMPERATURE DEGRADATION FACTORS @ 200°F REF. MIL-HDBK-5

$F_{tu} = .91$; $F_{ty} = .86$

$F_{ty} = 150,000 \times .86 = 129,000$ PSI

$M.S = \frac{129000}{114318} - 1 = +.13$

NOTE :- ALL OTHER ELEMENTS IN THE TITANIUM THROAT RETAINER HAD STRESS LEVELS WELL BELOW THAT CALCULATED AT ELEMENTS 121, 122 & 123.

SUBJECT: SSRM RETAINER THROAT DWG 1147003

DATE

WORK ORDER

BY

CHK BY

DATE

RETAINER THROAT CONT.

SECTION B-B (FIG 3.2.2.1

FROM COMPUTER ANALYSIS THE AVERAGE SHEAR STRESS ALONG B-B

ELEM.	STRESS PSI	WIDTH	LOAD
66	68,900	.25"	17225
47	36,000	.30	10800
29	17,300	.25	4325
19	11,500	.075	863
10	8310	.175	1454
3	2090	.31	648
			35,315

$$\sigma_{AV} = \frac{35,315}{1.36} = \underline{26,000 \text{ PSI}}$$

MAX STRESS AT THIS LOCATION IS AT ELEMENT 66

= 72,700 PSI

$$M.S. = \frac{129,000}{72,700} - 1 = +\underline{.77} \text{ @ TIME 750 SECS}$$

M.S $_{SHEAR}$ = HIGH

SECTION C-C (FIG 3.2.2.1)

MAX STRESS = 37,500 PSI

M.S. = HIGH

SSRM THROAT PINTLE

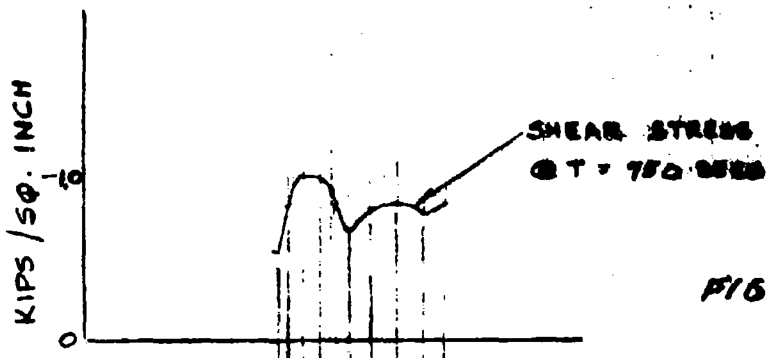


FIG 3.2.4.1

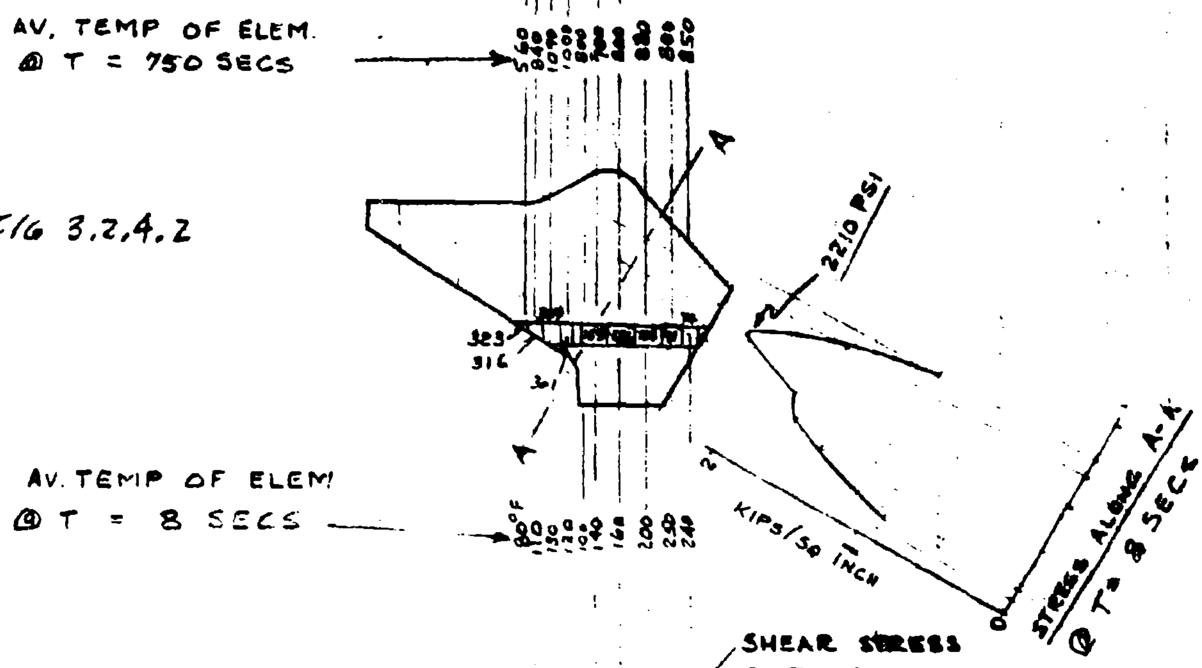


FIG 3.2.4.2

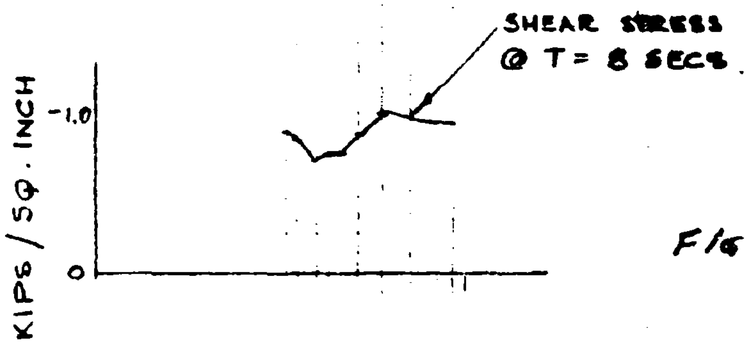


FIG 3.2.4.3

$F_{STR} = 2700$ PSI REF p 3.1.1.1

$$M.S. = \frac{2700}{2210} - 1 = .24$$

SRM THROAT PINTLE TIME 8 SECS

FIG 3.2.4.4

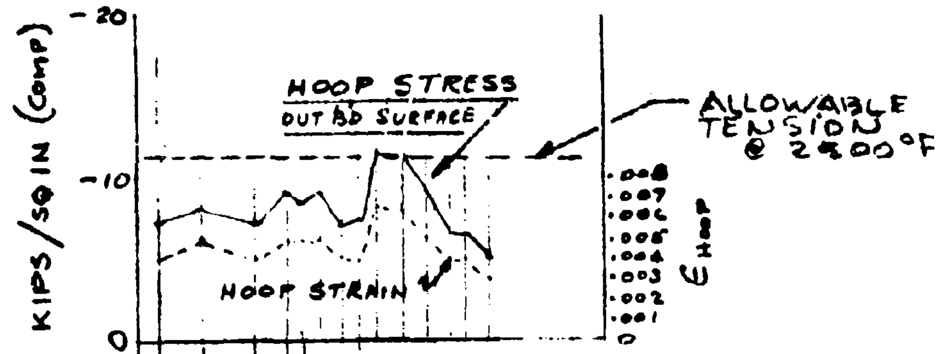


FIG 3.2.4.5

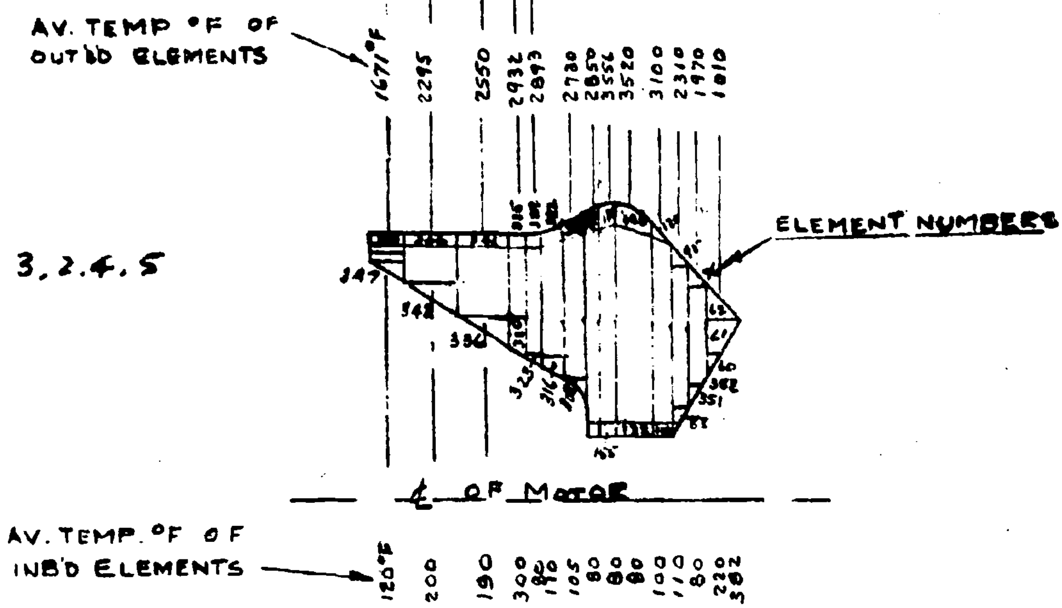
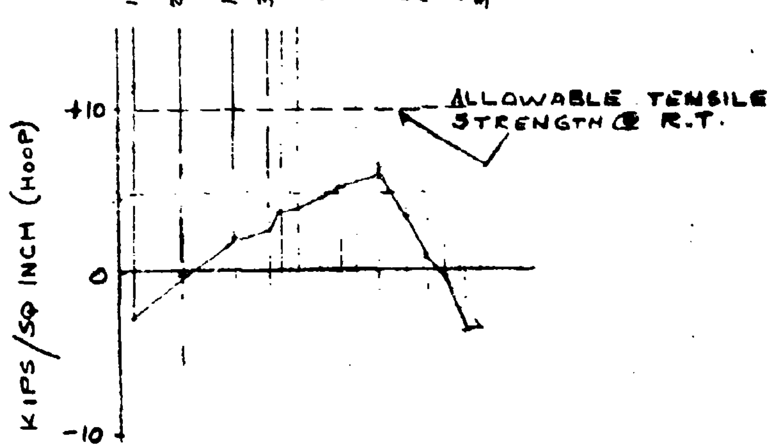


FIG 3.2.4.6



M.S. = 0.0

HOOP STRESSES ALONG INBOARD SURFACE (ASCARB 101)

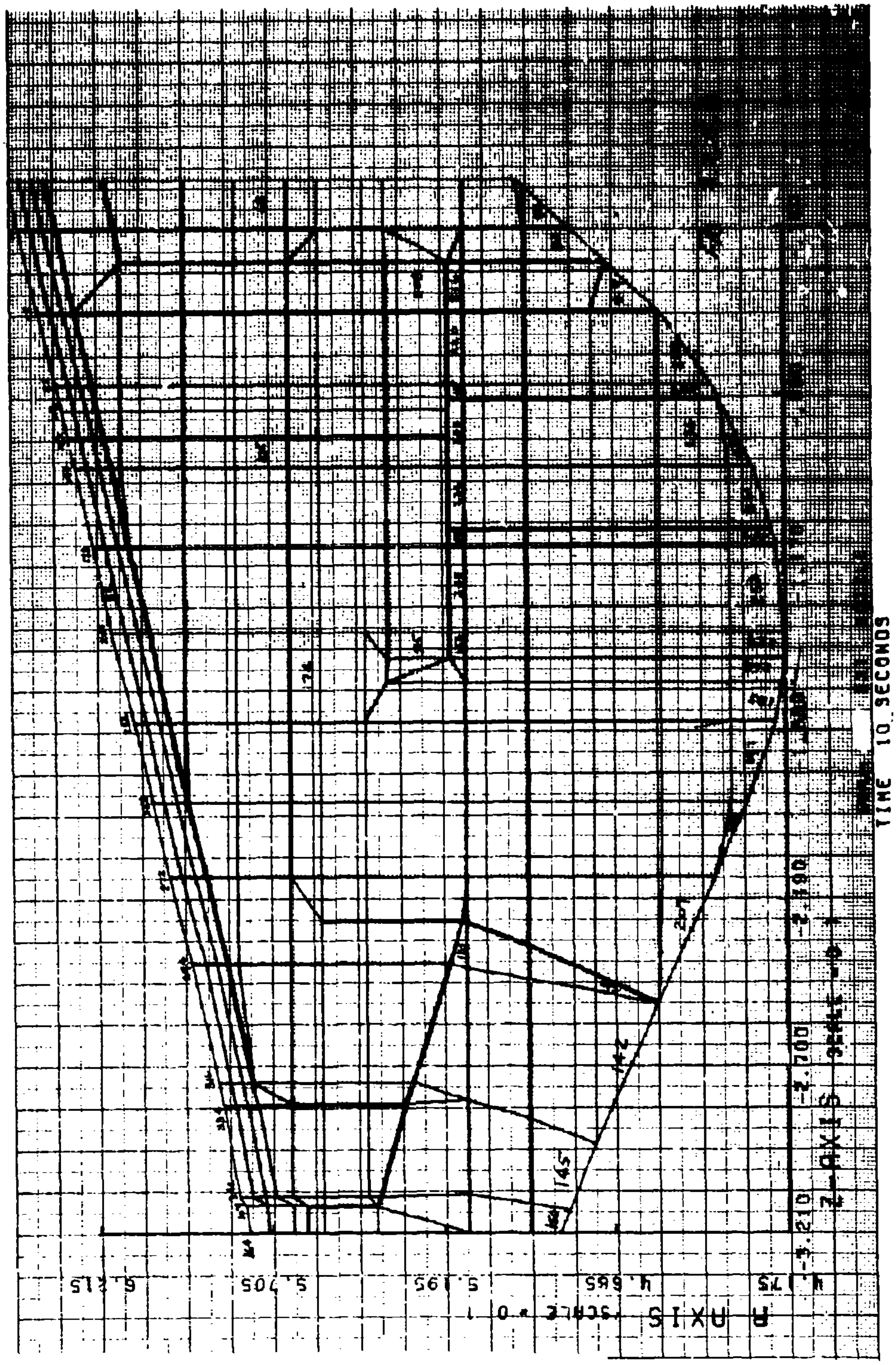
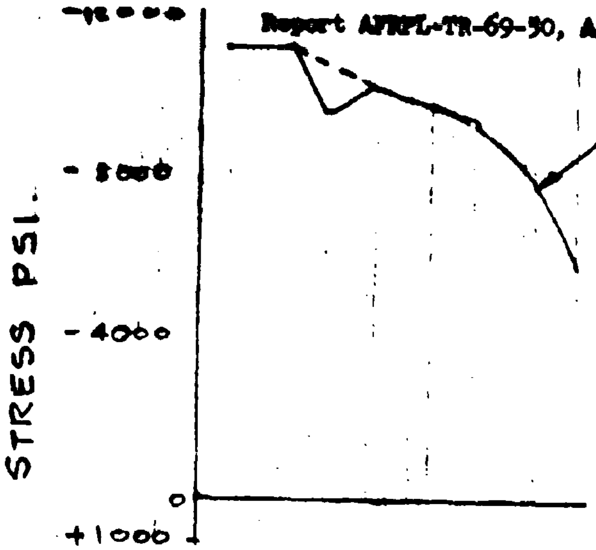

TIME 10 SECONDS
6.215
5.705
5.195
4.685
4.175
R AXIS
-3.210
-2.700
-2.190

Figure 3.2.5.0

FIG 3.2.5.1

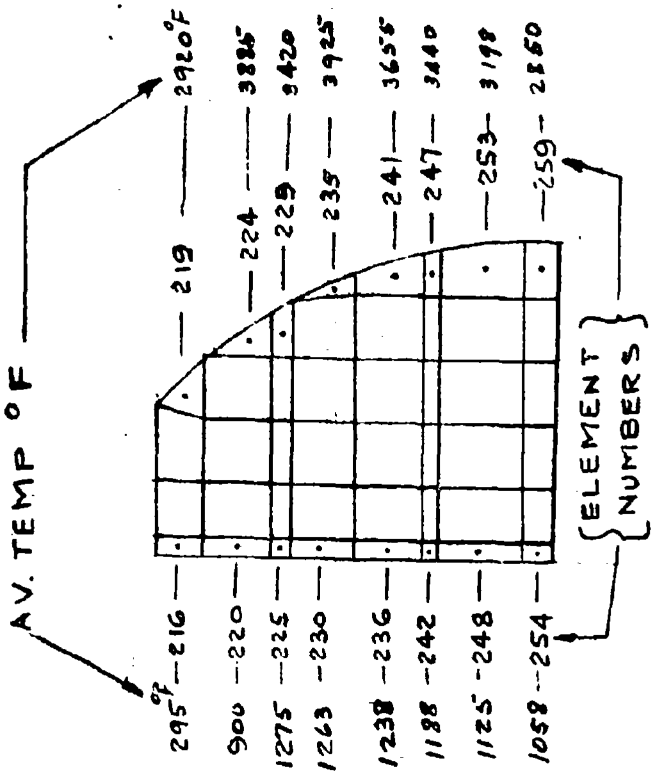


MAX f_H = 11,240 PSI @ 3000°F

F_H = 15,000 @ 3000°F

M.S. = $\frac{15.0}{11.24}$ - 1 = <u>.34</u>

FIG 3.2.5.2

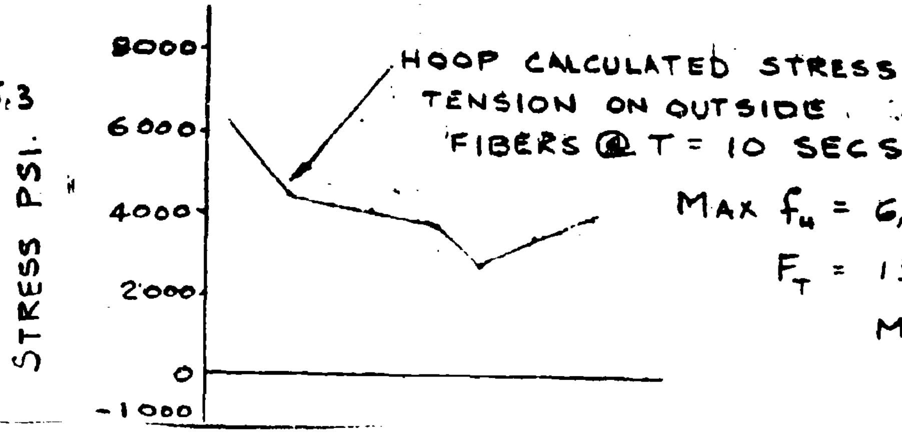


STRESS (HOOP) DISTRIBUTION @ T=10 SECS.

PYROLYTIC GRAPHITE EXTERNAL THROAT

SSR II NOZZLE

FIG 3.2.5.3



MAX f_H = 6,133 PSI @ 295°F

F_T = 13,000 psi

M.S. = $\frac{13.0}{6.1}$ - 1 = <u>1.13</u>

SSRM PROPELLANT
GRAIN STRESS ANALYSIS

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGC 2-643	REPORT NO.	PAGE 1 OF 9
SUBJECT SSRM .. PROPELLANT GRAIN STRESS ANALYSIS		DATE 20 SEPT. 68
		WORK ORDER 1221-14-40
BY J. W. STARK	CHK. BY	DATE

I. DESIGN

REFERENCE DRAWINGS

1146991
1146992

II DESIGN CRITERIA

A. LOADS

1. STORAGE

$T = 0°F$

$t = 30$ DAYS

2. FIRING

$T = 77°F$

$t_{IGNITION} = 155$ MSEC.

$p_{IGNITION} = 750$ PSIA.

$p_{MEOP} = 550$ PSIA.

B. MATERIAL PROPERTIES

1. MOTOR CASE

SHELL : AMS 6431 ; $t_{BARREL} = .070$ IN.
INSULATION : GEN-GARD 4010

$E_{CASE} = 29 \times 10^6$ PSI

$\alpha_{CASE} = 6.3 \times 10^{-6}$ IN./IN./°F

Preceding Page Blank

III.3.2

2. PROPELLANT GRAIN (REFERENCE (1))

a. AAP 3318

$T_{CURE} = 135°F$

$\alpha = 6.4 \times 10^{-5}$ IN./IN./°F

$E_{STORAGE} = 315$ PSI @ $T = 0°F$, $t = 30$ DAYS

$E_{FIRING} = 500$ PSI @ $T = 77°F$, $t = 155$ MSEC.

$E_{STORAGE} = 220$ PSI @ $T = 77°F$, $t = 24$ HRS

C. ALLOWABLES

1. AAP 3318

a. STORAGE (0°F)

(1) INNER BORE HOOP STRAIN

$\epsilon_{\theta} = 12\%$

(2) INTERFACE BOND STRESSES

$\sigma_{R} = 44$ PSI

$\tau_{RZ} = 28$ PSI

SUBJECT		REPORT NO.	PAGE
			DATE
			WORK ORDER
BY	CHK. BY		DATE

b. FIRING (77°F)

1) INNER BORE HOOP STRAIN

$\epsilon_\theta = 55\ \%$

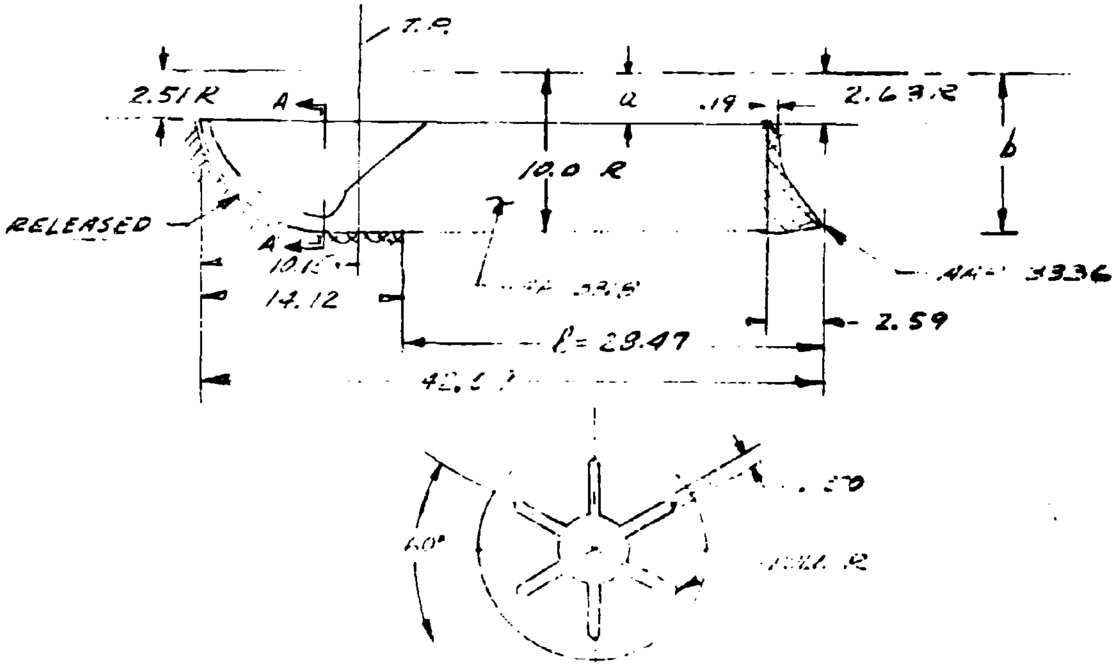
2) INTERFACE BOND STRESSES

$\tau_{rz} = 188$ PSI

II GEOMETRICAL PARAMETERS

A. GEOMETRY

FIG. 3.3.1



SECTION A-A

B. PARAMETERS

$$\frac{b}{a} = \frac{10.00}{2.63} = 3.80$$

$$\frac{l}{b} = \frac{28.47}{10.00} = 2.85$$

III ANALYSIS

A PRELIMINARY STRESS AND STRAIN ANALYSIS OF THE GRAIN IS CONDUCTED ON THE BASIS OF THE PARAMETRIC CURVES GIVEN IN REFERENCE (2).

A. ASSUMPTIONS

1. ASSUME CYLINDRICAL GRAIN SHAPE WITH 2.63 IN. BORE AND 28.47 IN. LENGTH.

2. FORWARD SECTION RELEASED PAST TANGENCY PLANE TO LOCATION WHERE FIN SLOTS TERMINATE.

3. AAP 3336 GRAIN LOCATED BETWEEN 0 - 9 % OF GRAIN LENGTH HAS MATERIAL PROPERTIES AND ALLOWABLES COMPARABLE TO AAP-3318.

E. PARAMETRIC STRESSES

1. STORAGE

a. AAP 3318

$\epsilon_\theta = 4.15\ \%$

$\sigma_R = 67.9$ PSI

$\tau_{Rz} = 18.5$ PSI

b. AAP 3336

$\epsilon_\theta = 2.08\ \%$

$\sigma_R = 67.9$ PSI

$\tau_{Rz} = 18.5$ PSI

2. FIRING

a. AAP 3318

$\epsilon_\theta = 2.86\ \%$

$\tau_{Rz} = 10.3$ PSI

b. AAP 3336

$\epsilon_\theta = 1.73\ \%$

$\tau_{Rz} = 10.3$ PSI

C. BASIC STRESSES

1. STORAGE

$\Delta T = -[135-0] = -135\ °F$

a. AAP 3318

$\epsilon_\theta = 4.15 \times \frac{-135}{-79} = 7.1\ \%$

$\sigma_R = 67.9 \times \frac{315}{1000} \times \frac{-135}{-79} = 37$ psi

$\tau_{RZ} = 18.5 \times \frac{315}{1000} \times \frac{-135}{-79} = 10.0$ psi

b. AAP 3336

$\epsilon_\theta = 2.08 \times \frac{-135}{-79} = 3.6\ \%$

$\sigma_R = 67.9 \times \frac{315}{1000} \times \frac{-135}{-79} = 37$ psi

$\tau_{RZ} = 18.5 \times \frac{315}{1000} \times \frac{-135}{-79} = 10.0$ psi

2. FIRING 77°F

$\Delta T = -[135-77] = -58\ °F$

a. AAP 3318

$\epsilon_\theta = 2.9\ \%$

$\epsilon_{\theta_{TEMP}} = 4.15 \times \frac{-58}{-79} = 3.0\ \%$

$\epsilon_{\theta_{TOTAL}} = 2.9 + 3.0 = 5.9\ \%$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGC 2-048	REPORT NO.	PAGE 7 OF
SUBJECT		DATE
		WORK ORDER
BY	CHK. BY	DATE

$$\tau_{rz} = 10.3 \times \frac{500}{1000} = 5.2 \text{ PSI}$$

$$\tau_{rz_{TOTAL}} = 18.5 \times \frac{220}{1000} \times \frac{-58}{-79} = 3.0 \text{ PSI}$$

$$\tau_{rz_{TOTAL}} = 5.2 + 3.0 = 8.2 \text{ PSI}$$

b. HAP 3336

$$\epsilon_\theta = 1.7\%$$

$$\epsilon_{\theta_{TEMP}} = 2.08 \times \frac{-58}{-79} = 1.5\%$$

$$\epsilon_{\theta_{TOTAL}} = 1.7 + 1.5 = 3.2\%$$

$$\tau_{rz_{TOTAL}} = 8.2 \text{ PSI}$$

D. MINIMUM MARGINS OF SAFETY

THE MAXIMUM STRESSES AND STRAINS WITH CORRESPONDING MARGINS OF SAFETY ARE GIVEN IN FIGURE 3.3.2 THE MINIMUM MARGIN OF SAFETY WAS DETERMINED TO BE 1.19 FOR THE PROPELLANT-INSULATION BOND TENSILE STRESS DURING STORAGE AT 0°F

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGC 2-800

SUBJECT		REPORT NO.	PAGE 8 OF
			DATE
			WORK ORDER
BY	CHK. BY		DATE

IV. REFERENCES

1. MEMORANDUM TO C.T. LEVINSKY FROM G.J. SVOB, SUBJECT: "STRUCTURAL INTEGRITY EVALUATION OF SSCM PROPELLANT/LINER SYSTEM", MEMO. NO. 3044-0740, DATED 17 SEPT. 1968

2. AEROJET STRUCTURES MANUAL

Summary of Propellant Grain

Stress Analysis

CONDITION	INNER BORE TENSILE HOOP STRAIN (%)			BOND SHEAR STRESS (PSI)			BOND TENSILE STRESS (PSI)		
	MAXIMUM	ALLOWABLE	M.S.	MAXIMUM	ALLOWABLE	M.S.	MAXIMUM	ALLOWABLE	M.S.
STORAGE * (30 DAYS @ 0°F)	7.1	12	+.69	10	28	+1.8	37	44	+.19
FIRING (P = 750 PSIA @ 77°F t_{IGN} = .155 SEC.)	5.9	55	HIGH	8	188	HIGH	COMPRESSIVE		

* T_{CURE} = 135°F

FIGURE 3.32

APPENDIX B

STRESS ANALYSIS OF TWENTY-PULSE IGNITER FOR STOP/START ROCKET MOTOR

STRESS ANALYSIS OF THE TWENTY-PULSE IGNITER

I. INTRODUCTION

A. SUMMARY OF RESULTS

The table on Page I-2 and I-3 is a summary of the minimum margins of safety. The minimum margin occurs in the threaded portion of the aft closure.

B. METHODS OF ANALYSIS

This report uses two methods of analysis. The basic design was checked using conventional discontinuity pressure vessel analysis (Ref: Kellogg Report - 9th Army-Navy-Air Force Solid Propellant Meeting, Structural Analysis for Design of Lightweight Rocket Shells).

As time permitted later in the design effort, AGC computer program E-11405 was used as a final check. This is a finite element technique which can incorporate arbitrary pressure and geometry of the igniter.

SUBJECT

TABLE OF MARGINS OF SAFETY

STRUCTURE	TYPE STRESS	MARGIN OF SAFETY	REF. PAGE
	CROWN SECTION SHEAR LIP	HIGH	3.A.4
FWD CLOSURE AND BARREL	CROWN SECTION BENDING	+1.3	3.A.4
	BOSS HOOP STRESS	+.27	3.B.1
	BOSS MERIDIONAL STRESS	+.29	3.A.11
	BARREL HOOP STRESS	+.03	3.B.2
	BARREL MERID. STRESS	+.96	3.B.2
AFT CLOSURE	THREADED JOINT HOOP STRESS	+.004	3.C.1
	THREADED JOINT MERID. STRESS	+.51	3.C.3
	THREAD SHEAR	HIGH	3.C.3
	JOINT BENDING & TENSION	+.17	3.C.7
	MEMBRANE STRESS	+.28	3.C.8
	FLANGE BOLT STRESS	HIGH	3.C.9
	FLANGE BENDING	+.64	3.C.11
	THROAT SUPPORT STRUCT. STRAIN	HIGH	3.C.10
	EXIT CONE SHEAR (STEEL)	HIGH	3.D.3
	EXIT CONE BENDING (STEEL)	+.51	3.D.4
	FASTENER NAS-[illegible]	HIGH	3.D.8
PLASTIC PARTS	SHEAR IN MX 2625 IN EXIT CONE	HIGH	3.D.3
	BENDING IN MX 2625 IN EXIT CONE	+.04	3.D.4
	THROAT RETAINER SHEAR	+.23	3.D.1
	" " BENDING	+.03	3.D.2

PLASTIC PARTS (CONT'D)	EXIT CONE LINER SHEAR	HIGH	3 D.3
	" " " BENDING	HIGH	3. D. 4
	CLOSURE LINER ELONGATION	ADEQUATE	3. D. 6
	ENTRANCE CAP	NO LOADS	3. D. 6
	THROAT CLEARANCE REQ'D TO PERMIT FREE THERMAL EXPANSION	0.036"	3. D. 6
	INSULATOR HOOP STRAIN	+ .90	3. D. 7

SECTION II DESIGN CRITERIA

A LOADS : 20 CYCLES

MAX. EXPECTED OPERATING PRESS (MEOP) 3000 PSI

THRUST 1500#

FACTOR OF SAFETY (SF) = 1.25

DESIGN LOAD 1.25 × 3000 PSI = 3750 PSI

THRUST 1.25 × 1500# = 1875#

B MATERIAL PROPERTIES :-

4130 STEEL

F_{tu} = 180,000 PSI

F_{ty} = 163,000 PSI

F_{su} = 109,000 PSI

$E = 29 \times 10^6$ PSI

C. GEOMETRY

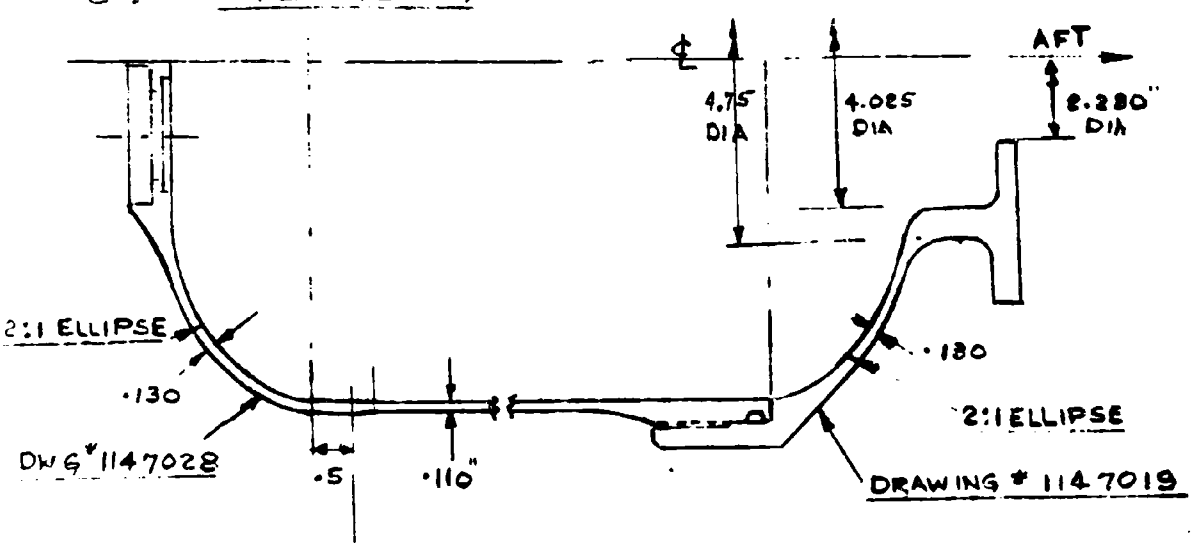
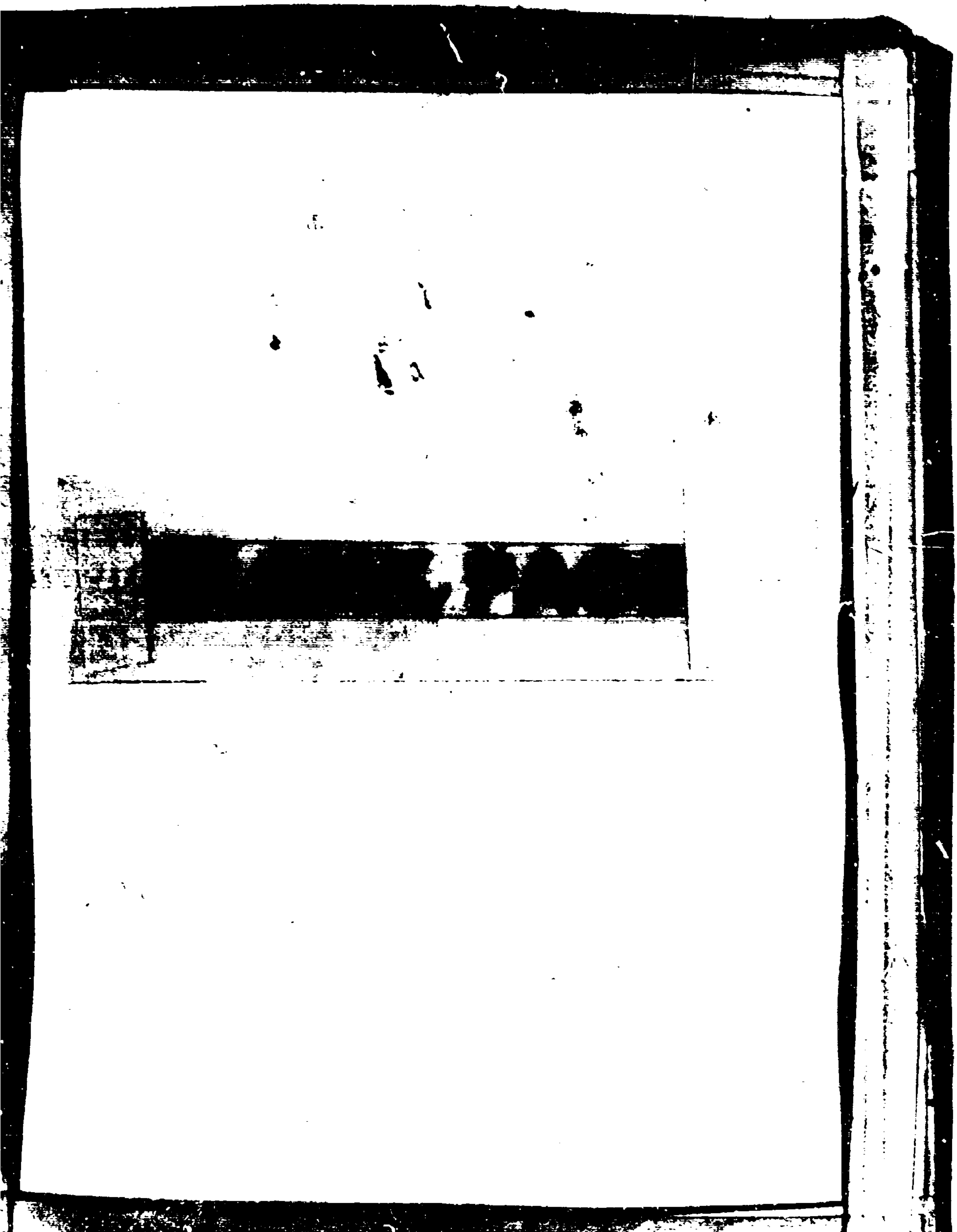


FIGURE II-1



SECTION III STRESS ANALYSIS

A. FWD BOSS AREA
B. FWD CLOSURE & BARREL
C. AFT CLOSURE
D. PLASTIC COMPONENTS

Preceding Page Blank

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

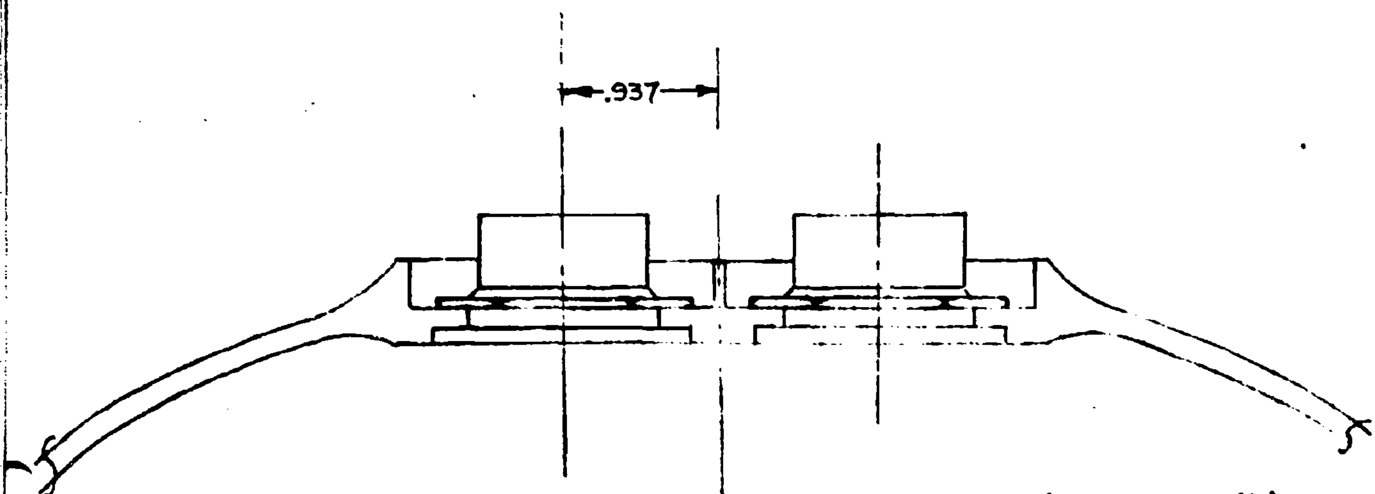
ABCS-0000-11

REPORT NO.	PAGE 3.A OF
SUBJECT: SECTION III-A FWD BOSS AREA	DATE
	WORK ORDER
BY: J. KOVACS / CHK. BY:	DATE: 7/16/68

REVISED BY W.A. BURNHAM 10-28-68

DWG 1147028

IGNITER PERFORATED CLOSURE



p_i = 3750 PSI (DESIGN PRESSURE)

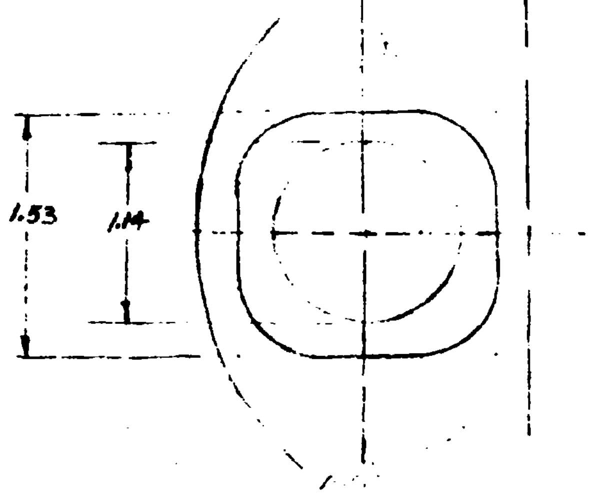
MATERIAL: 4130 STEEL

F_{ty} = 163000 PSI

F_{tu} = 180000 PSI

$E = 30 \times 10^6$ PSI

FULL SCALE

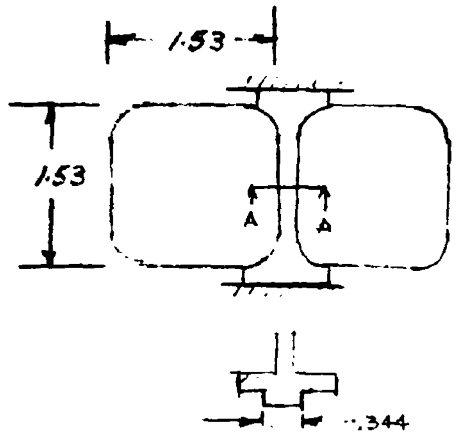


BOTTOM VIEW

FIG III-1

IGNITER PERFORATED CLOSURE - CONT'D

IT IS APPARENT THAT THE CROWN SECTION MID-WAY BETWEEN THE TWO PERFORATIONS IS A CRITICAL AREA. FOR THE PURPOSE OF PRELIMINARY ANALYSIS THE BEST IDEALIZATION OF THE STRUCTURAL RESPONSE IS TO CONSIDER THE MIDDLE STRIP AS A BEAM HAVING THE INDICATED SECTION, LENGTH AND LOADS AS FOLLOWS:



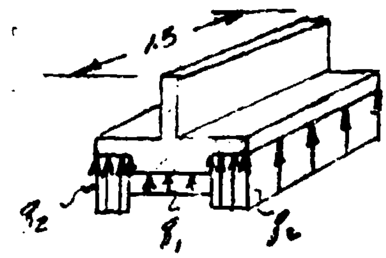


FIG III - 2

TOTAL EJECTION LOAD ON ONE PORT AREA:

$P = 3750\,(1.53)(1.53) = 8780$ LBS.

PERIPHERY LOAD (EJECTION) $= \frac{8780}{6} = 1460$ LBS/IN $= q_2$

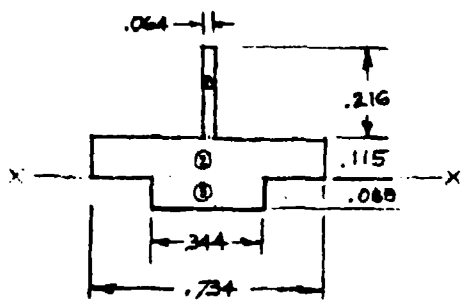
$q_1 = .344\,(3750) = 1290$ LBS/IN

TOTAL BEAM BENDING LOAD. $q = 2q_2 + q_1 = 2(1460) + (1290)$
$= 4210$ LBS/IN

TOTAL BEAM LOAD $P = 4210\,(1.53) = 6440$ LBS

IGNITER PERFORATED CLOSURE · CONT'D

FIG III-3



$A_1 = .064(.216) = .0139$ $\quad Y_1 = .273$ FROM X-X

$A_2 = .115(.734) = .0845$ $\quad Y_2 = .0575$

$A_3 = .069(.344) = .0237$ $\quad Y_3 = -.0345$

$$I_{0_1} = \frac{.064(.216)^3}{12} = .0000537$$

$I_{0_2} = \frac{1}{3}(.734)(.115)^3 = .000372$ (ABOUT X-X)

$I_{0_3} = \frac{1}{3}(.344)(.069)^3 = .0000377$ ABOUT (X-X)

	A	Y	AY	AY^2	I_0	$\lvert Y-\bar{Y}\rvert$	$(Y-\bar{Y})^2A$	$I_0 + A(Y-\bar{Y})^2$
	.0139	.273	.00380	.00104	.0000537	.2088	.000606	.00066
	.0845	.0575	.00486	.000280	.000372	.0067	—	.00372
	.0237	-.0345	-.000818	.000028	.0000038	.0987	.00023	.00027
Σ	.1221		.00784					.00465

$$\bar{Y} = \frac{\Sigma AY}{\Sigma A} = \frac{.00784}{.1221} = .0642 \text{ IN. UP FROM X-X}$$

NEUTRAL AXIS AT $.216 + (.115 - .0642)$
$= .267$ FROM TOP

$$I = \Sigma\left[I_0 + A(Y-\bar{Y})^2\right] = .00465$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

J600-11

REPORT NO.

PAGE

DATE

WORK ORDER

DATE

SUBJECT

IGNITER

BY

CHK. BY

IGNITER PERFORATED CLOSURE - CONT'D

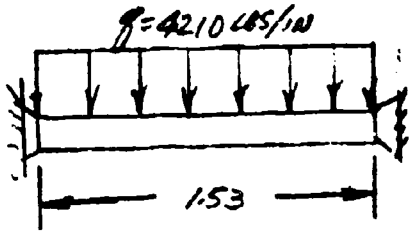


FIG III-4

SIMPLY SUPPORTED BEAM

$$M_{max} = \frac{q l^2}{8} = \frac{4210(1.53)^2}{8} = 1230 \text{ IN-LBS}$$

FIXED END BEAM

$$M_{max} = \frac{q l^2}{12} = \frac{4210(1.53)^2}{12} = 820 \text{ IN-LBS}$$

THE BEAM WILL APPROXIMATE THE FIXED END CONDITION, BUT ASSUME AV. OF TWO

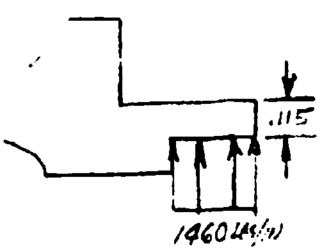
$$M_{MAX} = \tfrac{1}{2}(1230+820) = 1025 \text{ IN-LB}$$

$$\sigma_B = \frac{Mc}{I} = \frac{1025(.356)}{.00465} = \frac{365}{.00465} = 79{,}000 \text{ PSI}$$

$$M.S. = \frac{180{,}000}{79{,}000} - 1 = +1.3$$

\+ SUBSTANTIAL MARGIN OF SAFETY BASED ON CONSERVATIVE ANALYTICAL MODEL

SHEAR LIP:



$$\sigma_s = \frac{1460}{.115} = 12{,}700 \text{ PSI}$$

$F_{su} = 109{,}000$

M.S. = LARGE

FIG III-5

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0800-11	REPORT NO.	PAGE 3.45 OF
SUBJECT: IGNITER		DATE
		WORK ORDER
BY: J. KOVACS	CHK. BY	DATE

IGNITER BOSS - CLOSURE JOINT

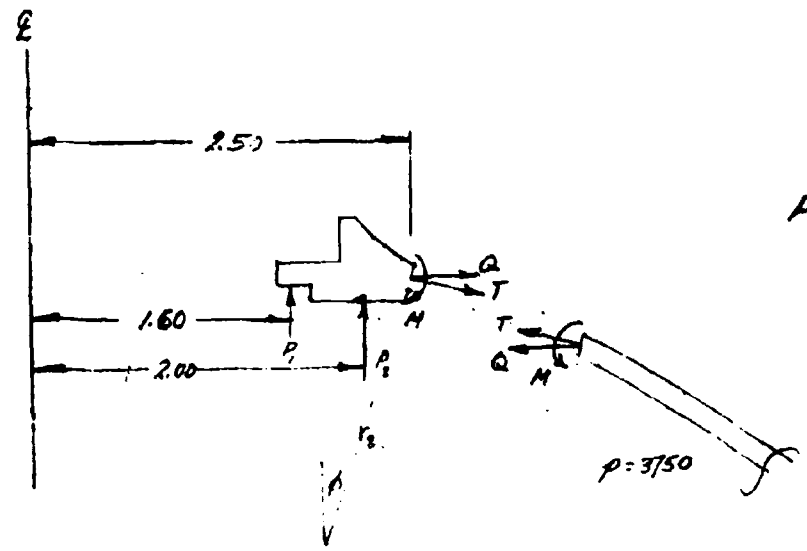


FIG III-6

$P_1 = \frac{pr}{2} = \frac{3750(1.60)}{2} = 3000$ LBS/IN

$P_2 = .66(3750) = 2470$ LB/IN

$\frac{r}{a} = \frac{2.50}{4.6} = .54$

$\frac{r_2}{a} = 1.74 \qquad r_2 = 1.74(4.6) = 8.00$ IN FOR 2:1 ELLIPSE

$\sin\phi = \frac{2.50}{8.00} = .312 \quad \therefore \phi = 18°$

$T = \frac{pr_2}{2} = \frac{3750(8.00)}{2}$ 15,000 LBS/IN

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGC8-0000-11

REPORT NO. | PAGE 3 | DATE | WORK ORDER

SUBJECT

BY | CHK. BY | DATE

IGNITER BOSS - CLOSURE JOINT - CONT'D

CROSS SECTION PROPERTIES:

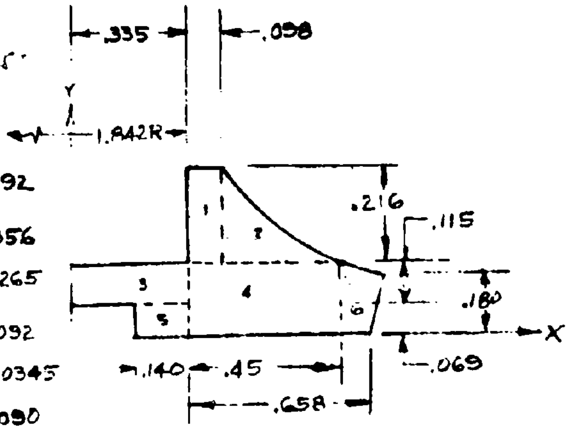


FIG III-7

$A_1 = .098(.216) = .0212 \qquad y_1 = .392$

$A_2 = \frac{1}{2}(.352)(.216) = .0380 \qquad y_2 = .356$

$A_3 = .335(.115) = .0385 \qquad y_3 = .1265$

$A_4 = (.184)(.45) = .0828 \qquad y_4 = .092$

$A_5 = .069(.140) = .0097 \qquad y_5 = .0345$

$A_6 = .208(.180) = .0374 \qquad y_6 = .090$

$I_{o1} = \frac{1}{12}(.098)(.216)^3 = .0000824 \qquad I_{o3} = \frac{1}{12}(.335)(.115)^3 = .000042 \qquad I_{o6} = \frac{1}{12}(.208)(.18)^3 = .000104$

$I_{o2} = \frac{1}{36}(.352)(.216)^3 = .000975 \qquad I_{o4} = \frac{1}{12}(.45)(.184)^3 = .000233$

ELEMENT	AREA	Y	AY	AY²	I_o	X	AX
1	.0212	.392	.00830	.00325	.0000824	.384	.0119
2	.0380	.356	.01350	.00482	.000975	.550	.0306
3	.0385	.1265	.0049	.00062	.000042	.167	.00643
4	.0828	.092	.0045	.00041	.000233	.560	.0464
5	.0097	.0345	.0003	.00001	—	.265	.00257
6	.0374	.090	.00337	.00030	.000104	1.097	.02415
Σ	.2276		.0349	.00941			.1290

$\bar{Y} = \frac{\Sigma AY}{\Sigma A} = \frac{.0349}{.2276} = .153 \text{ IN.} \qquad \bar{X} = \frac{\Sigma AX}{\Sigma A} = \frac{.1290}{.2516} = .513$

$I = \Sigma\left[I_o + A(Y-\bar{Y})^2\right]$

$I_1 = .0000824 + .0212(.239)^2 = .000203$
$I_2 = .000975 + .038(.203)^2 = .00255$
$I_3 = .000042 + .0385(.0265)^2 = .000312$
$\overline{.003065}$

$I_4 = .000233 + .0828(.061)^2 = .00054$
$I_5 = 0 + .0097(.1185)^2 = .00013$
$I_6 = .000104 + .0374(.063)^2 = .00025$
$\overline{.000930}$

$I = .003065 + .000930 = .00400$

IGNITER BOSS-CLOSURE JOINT-CONT'D

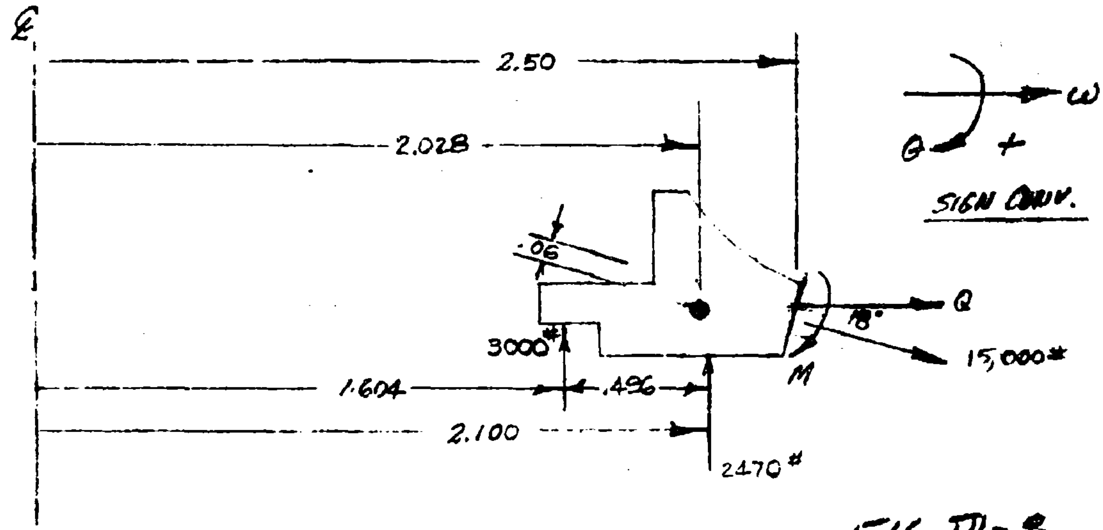


FIG III-8

BOSS DISPLACEMENT EQUATIONS:

$$E\theta_{CG} = \frac{r_{CG}}{I} \sum M_i r_i = \frac{2.028}{.00400} \sum M_i r_i = 507 \sum M_i r_i$$

$$Ew_{CG} = \frac{r_{CG}}{A} \sum Q_i r_i = \frac{2.028}{.2276} \sum Q_i r_i = 8.92 \sum Q_i r_i$$

$$\sum M_i r_i = 2.50\,M + 3000\,(.496)(1.604) + 15{,}000\,(.06)(2.50)$$

$$= 2.50M + 2390 + 2250 = 2.50M + 4640$$

$$E\theta_{CG} = 507\,[2.50M + 4640] = 1270\,M + 2{,}350{,}000$$

$$\sum Q_i r_i = 2.50Q + (15{,}000 \cos 18^\circ)(2.50)$$

$$= 2.50Q + 35{,}600$$

$$Ew_{CG} = 8.92\,[2.50Q + 35{,}600]$$

$$= 22.30Q + 317{,}000$$

IGNITER BOSS - CLOSURE JOINT - CONT'D

@ THE BOSS SHELL JUNCTION: $EW = EW_{CG} - X E\theta$

$X = \bar{Y} - \frac{.180}{2} = .153 - .090 = .063$

$$EW = 22.30\,Q + 317{,}000 - .063\,[1270\,M + 2{,}350{,}000]$$

$$= 22.30\,Q + 317{,}600 - (.80\,M + 148{,}000)$$

$$= -.80\,M + 22.30\,Q + 169{,}000$$

SHELL DISPLACEMENT EQUATIONS:

$$E\theta = -\frac{M}{D\beta} - \frac{Q}{2D\beta^2} + 2.65\frac{pr}{t}$$

$$EW = -\frac{M}{2D\beta^2} - \frac{Q}{2D\beta^3} + .2\frac{pr_1^2}{t}$$

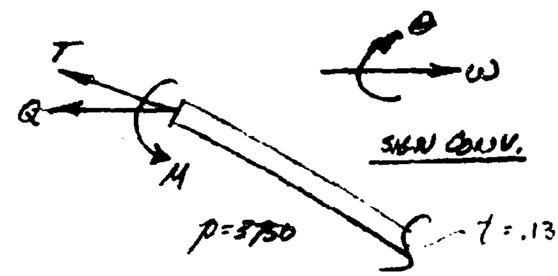


FIG III-9

$$\beta = \frac{1.285}{\sqrt{r_2 t}} = \frac{1.285}{\sqrt{8.0(.13)}} = \frac{1.285}{1.02} = 1.26 \quad \text{(FOR STL)}$$

$$D = \frac{t^3}{10.92} = \frac{(.13)^3}{10.92} = .000201$$

$D\beta = (.000201)(1.26) = .000253$

$D\beta^2 = (.000253)(1.26) = .000319$ $\qquad 2D\beta^2 = .000638$

$D\beta^3 = (.000319)(1.26) = .000402$ $\qquad 2D\beta^3 = .000804$

$\frac{1}{D\beta} = \frac{1}{.000253} = 3950$

$\frac{1}{2D\beta^2} = \frac{1}{.000638} = 1570$

$\frac{1}{2D\beta^3} = \frac{1}{.000804} = 1240$

$2.65\frac{pr}{t} = \frac{2.65(3750)(4.6)}{.13} = 352{,}000$

$.2\frac{pr^2}{t} = \frac{.2(3750)(4.6)^2}{.13} = 122{,}000$

AGNIETC

NEW.ZK ROGS - CLOSURE JOINT - CONT'D

$$E\theta = -3950M - 1570Q + 352{,}000$$
$$EW = -1570M - 1240Q + 122{,}000$$

EQUATING ROTATION AND DISPLACEMENT @ JUNCTION:

$$E\theta_{RING} = E\theta_{SHELL}$$

$$1270M + 2{,}380{,}000 = -3950M - 1570Q + 352{,}000$$
$$5220M + 1570Q + 1{,}000{,}000 = 0$$
$$M + .301Q + 191 = 0$$

$$EW_{RING} = EW_{SHELL}$$

$$-80M + 22.30Q + 169{,}000 = -1570M - 1240Q + 122{,}000$$
$$1490M + 1262Q + 47{,}000 = 0$$
$$M + .847Q + 31.6 = 0$$

$$\begin{cases} M + .301Q + 191 = 0 \\ M + .847Q + 32 = 0 \end{cases}$$
$$-.546Q + 159 = 0$$

$$Q = 291 \text{ LBS/IN}$$

$$M = -.301(291) - 191$$
$$= -278 \text{ IN-LB.}$$

STRESS @ $\frac{X}{a} = .54$

$t = .19$

Hoop Stress:

Direct Stress (Based on Radial Deflection)

$\omega E = -80M + 22.30Q + 169{,}000$ REF. P. 3A.8

where: $M = -278$ LB"/" REF. P. 3.A.9

$Q = 291$ LB/"

$f_{HD} = \epsilon E = \frac{\omega E}{R}$

$R = 2.50$

$$f_{HD} = \frac{-80(-278) + 22.30(291) + 169000}{2.50}$$

$$= \frac{22250 + 648 + 169{,}000}{2.50}$$

$$= 76{,}800 \text{ psi}$$

Bending Stress

$$f_{bH} = \pm 1.8 \frac{M}{t^2}$$

$$= \frac{1.8(278)}{(.19)^2} = \pm 13900 \text{ psi}$$

$$\Sigma f_H = 76800 + 13{,}900 = 90{,}700 \text{ psi}$$

$F_{ty} = 163{,}000$ psi

$$M.S. = \frac{163{,}000}{90{,}700} - 1 = +.80$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0000-11

REPORT NO.	PAGE 3.A.11 OF
SUBJECT	DATE
	WORK ORDER
BY H. EFFRON	CHK. BY	DATE

MERIDIONAL STRESS:

DIRECT STRESS:

$f_{DM} = \frac{T}{t}$

$T = 15{,}000$ #/in REF p 3.A.5

$t = .19$ "

$= \frac{15{,}000}{.19} = 79{,}000$ psi

BENDING STRESS:

$f_{BM} = \pm \frac{6M}{t^2}$

$M = 278$ in-#/in REF p

$= \frac{6(278)}{(.190)^2} = \frac{6(278)}{.0361} = \pm 47{,}500$ psi

$\Sigma f_M = 79{,}000 + 47{,}500 = 126{,}500$ psi

$F_{ty} = 163{,}000$ psi

$M.S. = \left(\frac{163}{126}\right) - 1 = +.29$

LENGTH OF TRANSITION

$\beta l = \frac{\pi}{2}$

$l = \frac{1.57}{\beta}$ $\beta = 1.26$ REF p 3.A.8

$= \frac{1.57}{1.26} = 1.25$

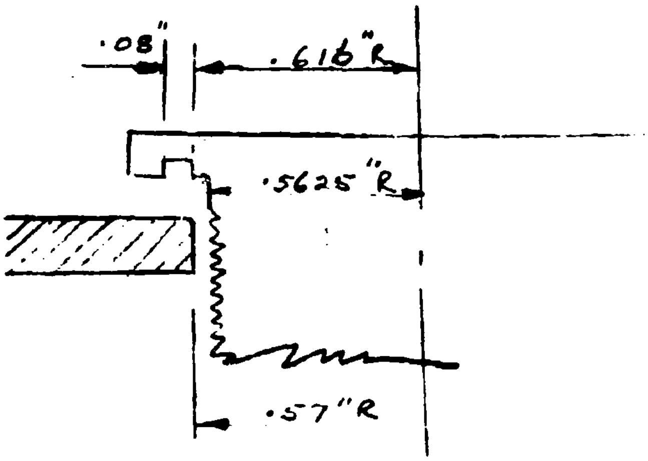
USE $l = 1.35$ "

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0000-11

SUBJECT		REPORT NO.	PAGE
RECEPTACLE CONNECTOR			DATE
			WORK ORDER
BY	CHK. BY		DATE

DESIGN PRESSURE 5000 PSI



CASE 22. TABLE X

$W = P\pi(.616+.04)^2 = 5000 \times \pi \times (.656)^2 = 6760^{\#}$

$b \;\; .5625$

$a = .57$

$$S_r = \frac{3W}{2\pi t^2}\left[\frac{2a^2(m+1)\log a/b + a^2(m-1) - b^2(m-1)}{a^2(m+1) + b^2(m-1)}\right]$$

$$= \frac{3\times 6760}{2\times\pi\times t^2}\left[\frac{2\times(.5625)^2(4.3)\log\frac{.57}{.5625} + (.57)^2(2.3) - (.5625)^2(2.3)}{(.57)^2(4.3) + (.5625)^2(2.3)}\right]$$

$$= \frac{3228}{t^2}\left[\frac{.035172 + .01955}{1.37707 + .72772}\right]$$

$S_r = \dfrac{83}{t^2}$ For $t = .089$ $S_r = 10,478$ PSI.

TOTAL LOAD = 6760*

$$\text{LOAD/INCH} = \frac{6760}{2\pi \times .5625} = 1914^{*}/\text{INCH}$$

$$f_s = \frac{3}{2} \times \frac{1914}{t} = \frac{2871}{t}$$

$$t = .094 \pm .005 = .089'' \text{ MIN}$$

$$f_s = \frac{2871}{.089} = 32{,}258 \text{ PSI}$$

F_{tu} = 56,000

F_{ty} = 33500

F_{su} = 35000 PSI

$$M.S = \frac{35000}{32258} - 1 = +.08$$

FOR 5700 PSI PRESSURE

20 PULSE IGNITER FWD CLOSURE & BARREL 10-28-68

MATERIAL STL 4130

F_{ty} = 163,000 PSI (MIN)

THE FORWARD CLOSURE AND PART OF THE CYLINDRICAL SECTION OF THE IGNITER CHAMBER WERE ANALYZED BY MEANS OF A DIGITAL COMPUTER PROGRAM FOR FINITE ELEMENT ANALYSIS AS DESCRIBED IN TECHNICAL MEMORANDUM NO. 33, AEROJET-GENERAL CORPORATION.

MAXIMUM EXPECTED OPERATING PRESSURE = 3000 PSI
FACTOR OF SAFETY = 1.25
DESIGN PRESSURE = 1.25 x 3000 = 3750 PSI

THE HIGHEST CALCULATED STRESS WAS IN ELEMENT 80, WHICH IS ADJACENT TO THE BOSS, HOOP DIRECTION. THIS CALCULATED STRESS WAS 187,200 PSI, WHICH IS GREATER THAN THE YIELD STRESS, HOWEVER, THE AVERAGE HOOP STRESS IN THE CROSS SECTION IS ONLY 120,000 PSI AND LOCAL YIELDING WILL PREVENT EXCESSIVE STRESSES IN ELEMENT 80, THE OUTSIDE ELEMENT.

THE AV. HOOP STRESS IN THE SECTION IS 119,500 PSI.
FOR t = .527. MIN. t = .490
FOR MIN. t, $\sigma_H = 119,500\left(\frac{.524}{.490}\right) = 127,000$ PSI

$$M.S. = \frac{163000}{127000} - 1 = +.27$$

THE HIGHEST HOOP STRESS AWAY FROM THE BOSS IS IN THE BARREL SECTION WHERE IT IS AS FOLLOWS:

EL.	1	159600 PSI
	2	156700
	3	157900
	4	157100
	5	156300
AV.		156100 BASED ON t = .110

FOR MIN. $t = .100$

$$\sigma_H = 158{,}100\left(\frac{.110}{.100}\right) = 174{,}000 \text{ PSI}$$

BASED ON NOMINAL THICKNESS $t = .110$

$$M.S. = \frac{163000}{158100} - 1 = +.03$$

THE HIGHEST MERIDIONAL STRESS OCCURS IN THE SECTION MADE UP OF ELEMENTS 26-30.

EL.	26	51,400 PSI
	27	63,400
	28	75,200
	29	87,200
	30	99,600
	AV.	75,360

BASED ON MIN. $t = .100$

$$\sigma_M = 75360\left(\frac{.110}{.100}\right) = 83{,}000 \text{ PSI}$$

$$M.S. = \frac{163000}{83000} - 1 = +.96$$

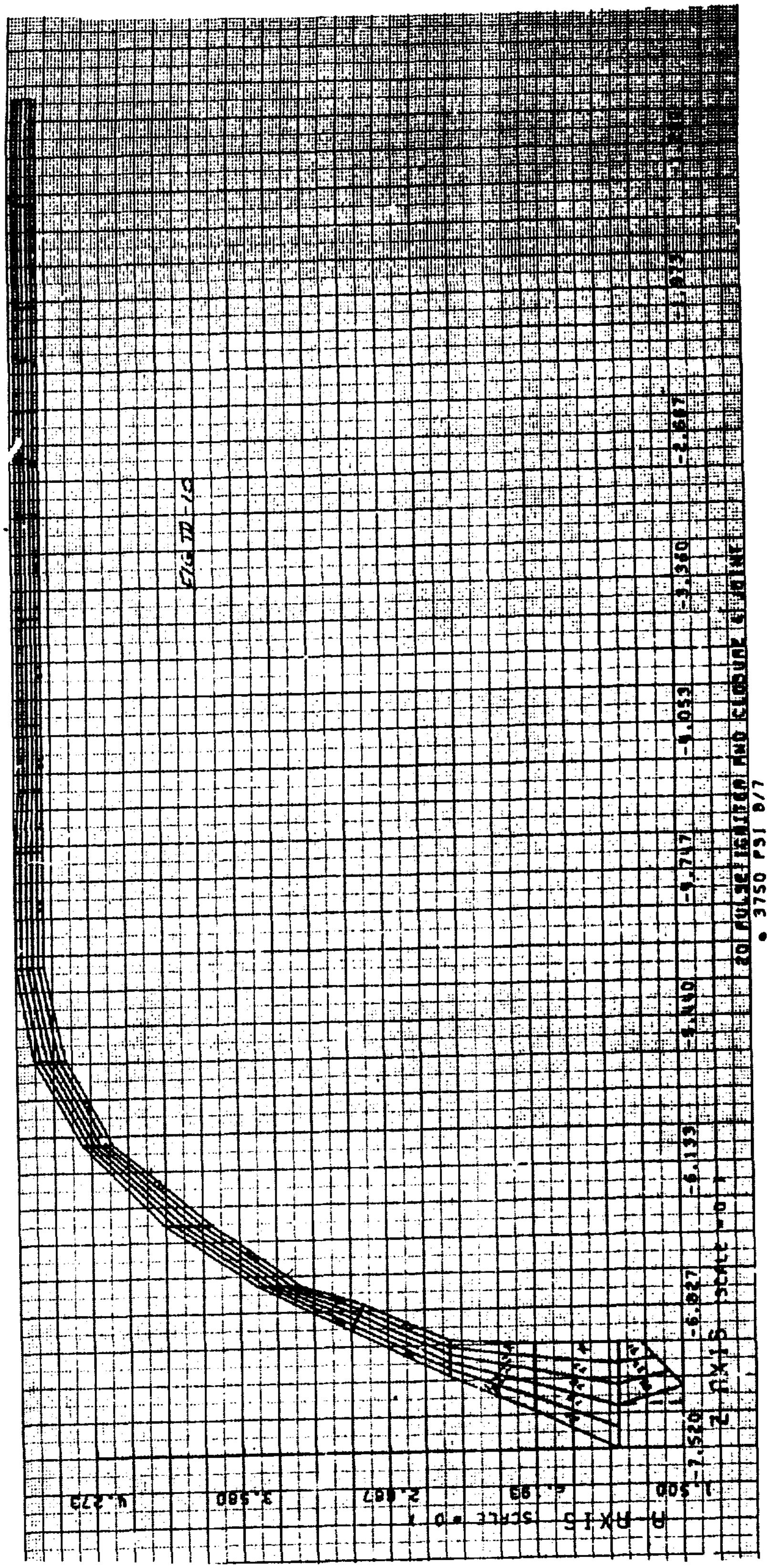


Figure III-10

20 PULSE IGNITER AFT CLOSURE JOINT

MATERIAL STEEL 4130

F_{ty} = 163000 PSI MIN.

REF. DRAWINGS 1147019 & 1147028

THE AFT CLOSURE THREADED JOINT WAS ANALYZED BY MEANS OF A DIGITAL COMPUTER PROGRAM FOR THE FINITE ANALYSIS OF SOLIDS WITH NONLINEAR MATERIAL PROPERTIES AS DESCRIBED IN TECHNICAL MEMORANDUM NO 23; AEROJET-GENERAL CORPORATION

MAXIMUM EXPECTED OPERATING PRESSURE = 3000 PSI

FACTOR OF SAFETY = 1.25

DESIGN PRESSURE = 1.25 x 3000 PSI = 3750 PSI.

THE HIGHEST STRESSES OCCURRED IN THE CYLINDRICAL SECTION AT ELEMENTS 131 THRU 135

ELEM. 131 σ_H = 163460 PSI
132 σ_H = 162920 PSI
133 σ_H = 162410 PSI
134 σ_H = 161900 PSI
135 σ_H = 161380 PSI
812070 PSI AVG = 162410 PSI FOR t = .110

MIN t = .110 − .010 = .100"

$$\sigma_H = \frac{162410 \times .11}{.10} = 178,650 \text{ PSI}$$

BASED ON NOMINAL THICKNESS t = .110"

$$M.S. = \frac{163000}{162410} - 1 = \underline{\underline{+.004}}$$

MERIDIONAL STRESS IN CLOSURE AT ELEMENTS 1 THRU 5

ELEM 1 σ_{JK} = 110000 PSI
2 σ_{JK} = 109000 PSI
3 σ_{JK} = 108000 PSI
4 σ_{JK} = 107000 PSI
5 σ_{JK} = 107000 PSI
AVERAGE = 108200 PSI FOR t = .130"

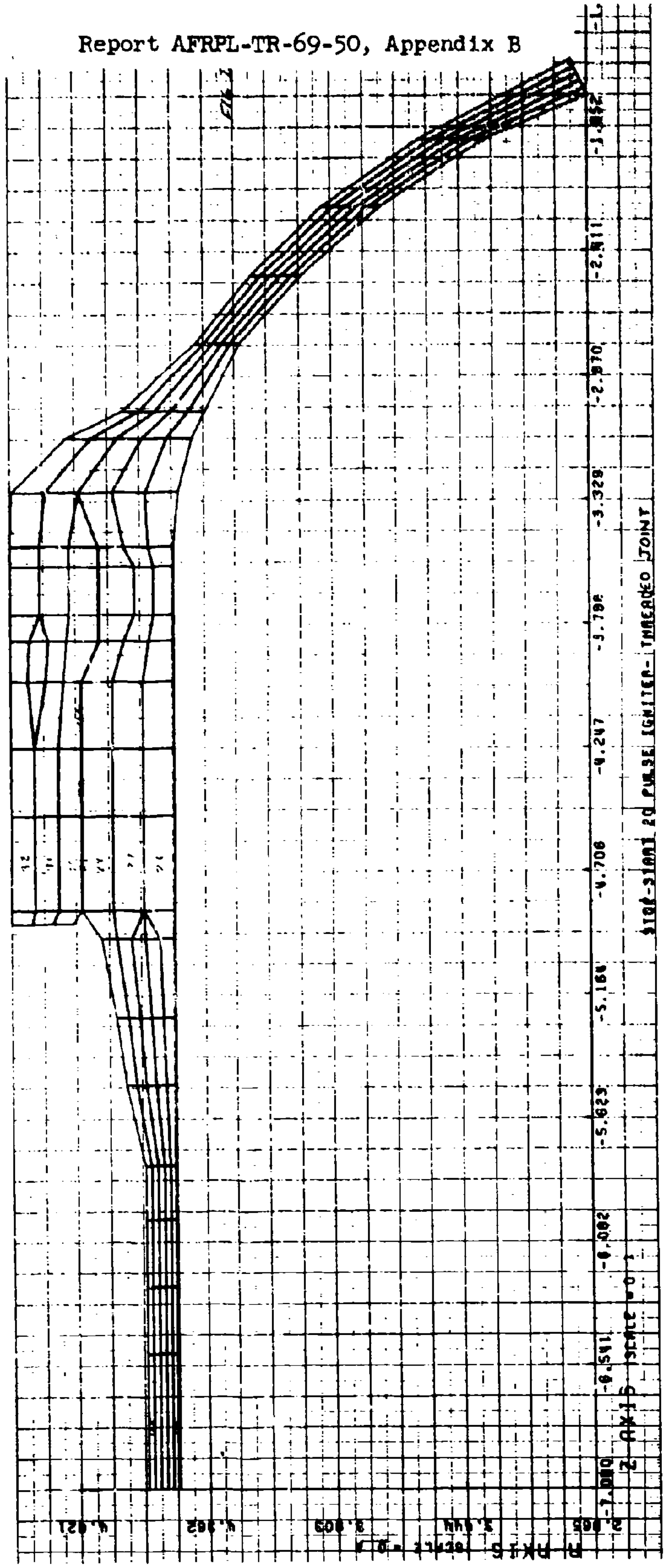


Figure III-11

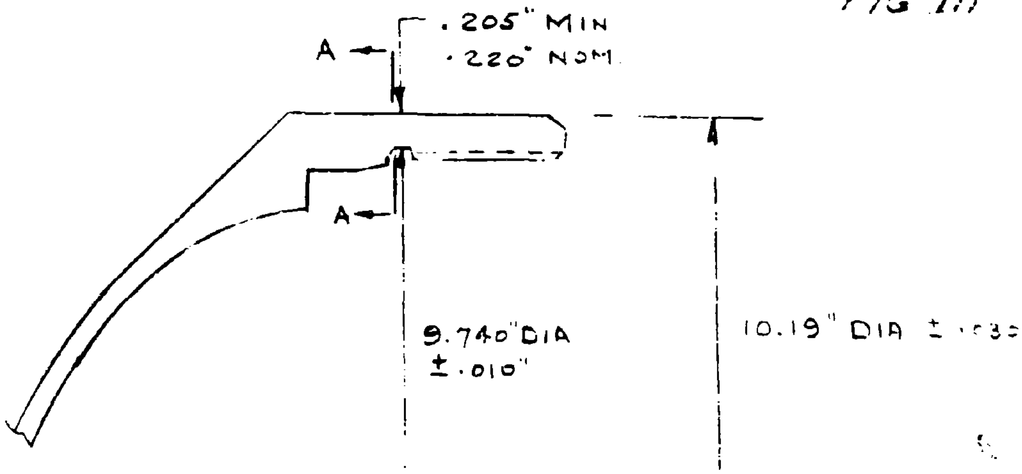
AFT CLOSURE CONT.

AVERAGE STRESS = 108 200 P.I   t = .130"

M.S. = $\frac{163000}{108200} - 1 = +.505$

THREADED JOINT

FIG III 12



F_s = 109,000 PSI

9.7 - 10 UNS - 2A THREADS

PITCH DIA = 9.63"

L = .864"

ASSUME FIRST & LAST THREAD TO BE INEFFECTIVE

THEN LENGTH OF ENGAGEMENT .864 - .2 = .664

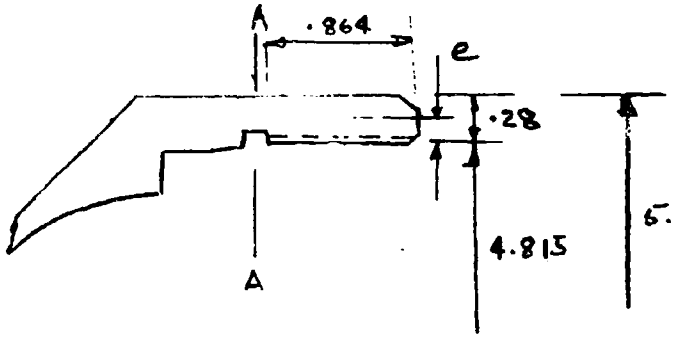
AREA IN SHEAR = .85 × .664 = .56

LOAD/INCH = $\frac{PR}{2} = \frac{3700 \times 4.9}{2} = 9113^{\#}$

$f_s = \frac{3}{2} \frac{P}{A} = \frac{1.5 \times 9113}{.56 \times 1} = 24,400$ PSI

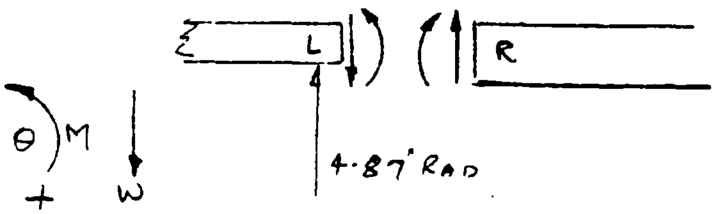
M.S = HIGH

THREADED JOINT CONT



MOMENT @ A-A

FIG III-13



$$\theta_L = \frac{1}{2D\beta^2} Q_L + \frac{1}{D\beta} M_L$$

$$W_L = -\frac{.85\,PR^2}{Et} + \frac{1}{2D\beta^3} Q_L - \frac{1}{2D\beta^2} M_L$$

$$\beta = \frac{1.285}{\sqrt{Rt}} = \frac{1.285}{\sqrt{4.87 \times .2}} = 1.3019$$

$$D = \frac{Et^3}{10.92} = \frac{29 \times 10^6 \times (.2)^3}{10.92} = .02124 \times 10^6$$

$$\frac{1}{D\beta} = \frac{1}{.02124 \times 1.3019} \times 10^{-6} = 36.16272\,(10^{-6})$$

$$\frac{1}{2D\beta^2} = 13.8882\,(10^{-6})$$

THREADED JOINT CONT

$$\frac{1}{2D\beta^3} = 10.66749 (10^{-6})$$

$$\theta_L = \left[-13.8882 Q_L + 36.16272 M_L \right] 10^{-6} \quad \text{——— (1)}$$

$$W_L = -\frac{.85 PR^2}{Et} + \frac{1}{2D\beta^3} Q_L - \frac{1}{2D\beta^2} M_L$$

$$W_L = \left[-5897 + 10.667 Q_L - 13.888 M_L \right] 10^{-6} \quad \text{——— (2)}$$

$$\theta_R = \frac{M_{CG} T^2}{E I_{YY}}$$

$$W_R = \left(\theta_R \times \frac{L}{2} \right) - \frac{QR^2}{EA}$$

$$I_{YY} = \frac{.864 \times .28^3}{12} = .00158 \text{ IN}^4$$

$$e = \frac{9.965 - 9.63}{2} = .1675''$$

$$P = \frac{PR}{2} = \frac{3750 \times 4.815}{2} = 9028 \ \#/\text{INCH}$$

$$M = 9028 \times .1675 = 1512 \text{ IN-LBS/INCH}$$

$$T = 4.9825$$

$$M_{CG} = \left(-M - Q\frac{e}{2} + 1512 \right)$$

$$\theta_R = \frac{(-M - .432Q + 1512)(4.9825)^2}{29 \times .00158} 10^{-6}$$

$$= 541.8 \times 10^{-6} (-M - .432Q + 1512)$$

$$\theta_R = \left[-541.8M - 234Q + 819202 \right] 10^{-6} \quad \text{——— (3)}$$

THREADED JOINT CONT.

$$W_R = \theta_R \times \frac{L}{2} - \frac{QR^2}{EA}$$

$$A = .866 \times .28 = .24248$$

$$\frac{QR^2}{EA} = \frac{Q\,(4.8925)^2}{29 \times .24248}\,10^{-6} = 3.03Q\,(10^{-6})$$

$$\frac{L}{2} = .432$$

$$W_R = .432\left[-541.8M - 234Q + 819202\right]10^{-6} - 3.03Q\,(10^{-6})$$

$$= \left[-234M - 101Q_R + 353895 - 3.03Q\right]10^{-6}$$

$$W_R = \left[-234M - 104Q_R + 35389\right]10^{-6} \qquad (4)$$

$$\theta_L = \theta_R$$

FROM (1) & (3)

$$-13.888Q + 36.162M = -541.8M - 234Q + 819202$$

$$577.96M + 220Q - 819202 = 0 \qquad (5)$$

$$W_L = W_R$$

FROM (2) & (4)

$$-5897 + 10.667Q - 13.888M = -234M - 104Q + 35389$$

$$220.1M + 114.7Q - 359792 = 0 \qquad (6)$$

MULT (6) × 1.918

$$422M + \cancel{220}Q - 690095 = 0$$

$$(5)\quad 577.96M + \cancel{220}Q - 819202 = 0$$

$$-155.96M + 129107 = 0$$

$$M = 828 \text{ IN LBS}$$

FROM (5)

$$479551 + 220Q - 819202 = 0$$

$$220Q = 340651$$

$$Q = 1548^{\#}$$

20 PULSE IGNITER

THREADED JOINT CONT

$$M = 828 \text{ IN-LBS/INCH}$$
$$Q = 1548^{\#}$$

$$\sigma_M = \frac{6M}{t^2} = \frac{6 \times 828}{(.205)^2} = 118,215 \text{ PSI}$$

$$\sigma_S = \frac{P}{A} = \frac{1548}{.205 \times 1} = 7550 \text{ PSI}$$

$$\sigma_t = \frac{PR}{2t} = \frac{3750 \times 4.87}{2 \times .205} = 44,543 \text{ PSI}$$

$$\sigma = \frac{P}{A} \pm \frac{MC}{I}$$

$$= 44543 \pm 118215 = 162758 \text{ PSI}$$

$$M.S. = \frac{1}{\frac{44543}{163000} + \frac{118215}{163000 \times 1.25}} - 1$$

$$.273 + .580$$

$$= +.17$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA
AGC3-0000-11

REPORT NO.

PAGE

DATE

WORK ORDER

DATE

SUBJECT

20 PULSE IGNITER

BY

CHK. BY

AFT CLOSURE DWG# 1147019

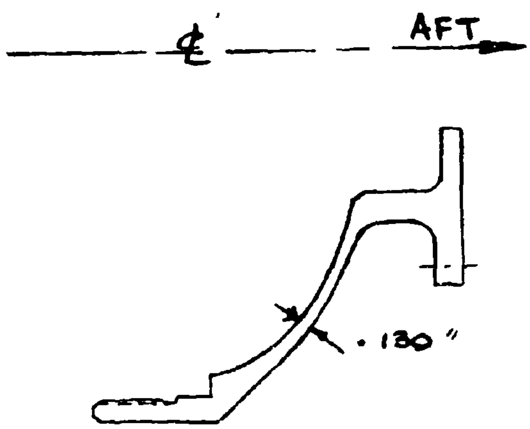


FIG IV-14

BASIC MEMBRANE REF AGC STRUCTURES MANUAL

$F_{ty} = 163000$ PSI

$R = 4.5''$

$a = 8.989$

$$\frac{R}{a} = \frac{4.5}{8.989} = .5$$

FOR 2:1 ELLIPSE $\frac{N\phi}{aP} = .9$; $\frac{N\theta}{aP} = .71$

FOR P = 3750 PSI

$$N\phi = .9 \times 3750 \times \frac{8.989}{2} = 15{,}170^{\#}$$

$$\sigma_\phi = \frac{15170}{(.130-.010)} = 126{,}420 \text{ PSI}$$ (BASED ON MIN. t)

$$M.S = \frac{163000}{126420} - 1 = \underline{\underline{+.28}}$$

AFT FLANGE DWG # 1147019

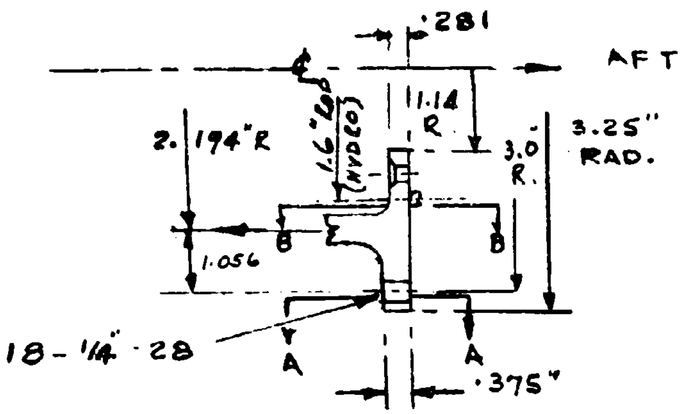


FIG III - 15

MATERIAL STEEL 4130

F_{ty} = 163,000 PSI (MIN.)

F_{tu} = 180,000 PSI

F_{su} = 109,000 PSI

LOADING CONDITIONS :-

(a) FIRING OF IGNITER $P_D = P_I \pi (1.14)^2 = 3750 . \pi . 1.3$

(b) " " MOTOR $P_D = P_M \pi (1.5)^2 = 690 . \pi . 2.25$

(c) HYDRO TEST $P_D = P_M \pi (1.6)^2 = \underline{3750 \pi \cdot 2.56}$ (CRIT.)

DIRECT BOLT LOAD $= \frac{3750 \times 2.56 \times \pi}{18} = 1676$ #

ASSUME P_K = 100% P_D

$P = 2 P_D = 2 \times 1676 = 3352$ #

$P_{ALL} = 6190$ #

M.S = High

20 PULSE IGNITER

AFT FLG CONT.

SECTION A-A

TOTAL BOLT LOAD = 3352#

PITCH OF BOLTS $= \frac{\pi \times 6.0}{18} = 1.047''$

METAL BETWEEN BOLTS $= 1.047 - .281$
$= .766''$

MOMENT ARM $= 3.25 - 3.0 = .25''$

MOMENT/INCH $= \frac{3352 \times .25}{.766} = 1094$ IN-LBS/IN

$$\sigma_b = \frac{6M}{t^2} = \frac{6 \times 1094}{(.375)^2} = 46{,}677 \text{ PSI}$$

$$M.S = \frac{163000}{46677} - 1 = HI$$

THROAT SUPPORT STRUCTURE

MAT'L 4130 STL.

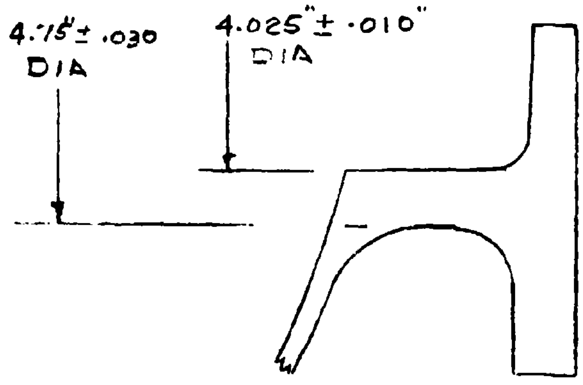


FIG III-16

$$\text{MIN } t = \frac{4.72 - 4.035}{2} = .342''$$

CRITERIA STRAIN $\leq .0025$

$$\epsilon = \frac{PR}{2tE}$$

$$= \frac{3750 \times 2.017}{2 \times .342 \times 29} \times 10^{-6}$$

$$= 381 \times 10^{-6}$$

M.S = HI

AFT FLG CONT.

SECTION "B-B" IGNITER FIRING

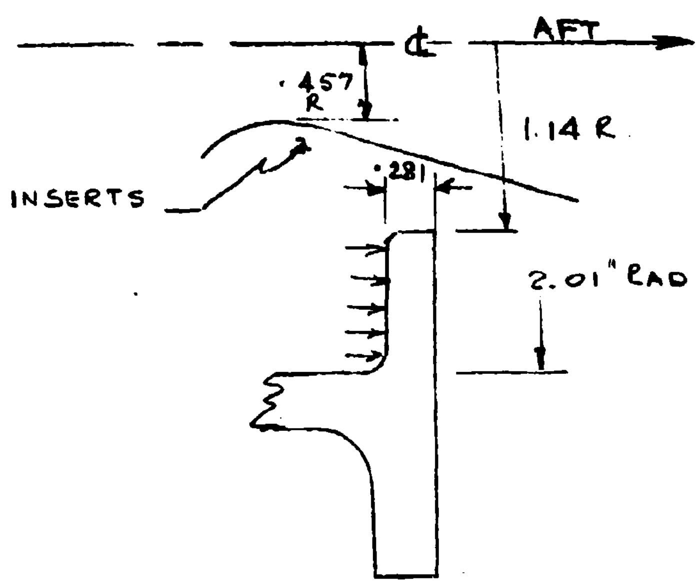


FIG III-17

EVALUATING p TO REFLECT LOAD ON THE INSERTS

$$p = \frac{3750\,\pi\,(2.01^2 - .457^2)}{\pi\,(2.01^2 - 1.14^2)} = 5243 \text{ PSI}$$

STRESS:- REF ROARK TABLE X CASE 17

$$a/b = \frac{2.01}{1.14} = 1.75$$

$$f_b = \frac{\beta w a^2}{t^2}$$

β FOR S_r = .370
w = 5243
t = .281

$$f_b = \frac{.37 \times 5243 \times (2.01)^2}{(.281)^2} = \underline{99{,}260 \text{ PSI}}$$

$$M.S = \frac{163000}{99260} - 1 = +.64$$

RETAINER IGNITER THROAT DWG 1147021

MATERIAL WB 8217 CARBON PHENOLIC (REF W.B CATALOG.)

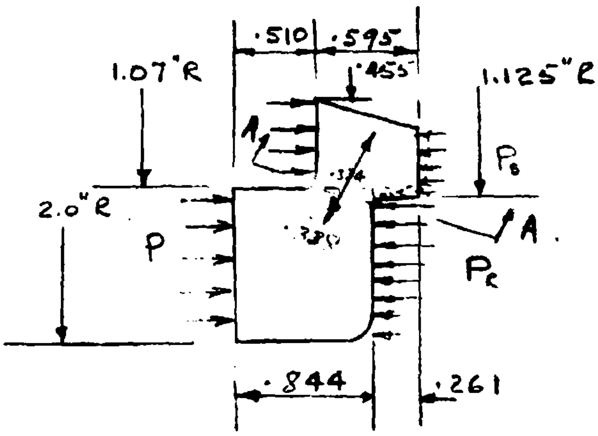


FIG III - 18

@ SECTION A-A.

ESTIMATE OF EJECTION LOAD @ P = 3750 PSI
& P_s = 450 PSI

$$P_{EJ} = \pi(1.07^2 - .455^2)(3750 - 450) = 3095\pi^{\#}$$

SHEAR @ SECT A-A

$$f_s = \frac{3}{2}\frac{P_{EJ}}{A} \qquad A = 2\pi R t = 2\pi \times 1.07 \times .338 = .723\pi$$

$$f_s = \left(\frac{3}{2}\right)\frac{3517}{.723} = 7296 \text{ PSI}$$

$$F_s = .5 F_t = .5(18,000) = 9000 \text{ PSI}$$

$$M.S. = \frac{9000}{7296} - 1 = +.23$$

BENDING @ SECT. A-A

$$f_b = \frac{6M}{t^2}$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0600-11

REPORT NO.

PAGE 3.0.2 OF

SUBJECT

DATE

20 PULSE IGNITER

WORK ORDER

BY

CHK. BY

DATE

RETAINER IGNITER THROAT CONT.

$$M = \frac{P_{EJ}}{2\pi R}\overset{.145}{\left[(1.125+.03) - (1.070-.06)\right]}$$

$$= \frac{3095 \times .145}{2.14} = 210 \text{ "\#/IN}$$

$$t = .338$$

$$f_b = \frac{6M}{t^2} = \frac{6 \times 210}{(.338)^2} = 11{,}030 \text{ PSI}$$

$$F_b = 18{,}000 \text{ PSI}$$

$$M.S. = \frac{18{,}000}{11{,}030} - 1 = \underline{\underline{+.63}}$$

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

ABCS-0600-11

REPORT NO.

PAGE 3.D.3 OF

DATE 10/15/68

SUBJECT

Exit Cone, Igniter SK 101568

WORK ORDER

BY H. Efron

CHK. BY

DATE

Exit Cone Liner - 1st Revision MX 2625

Shear-out - MX 2625

$$f_s = \frac{P_{FJ}}{A_{S.O.}}$$

$P_{FJ} = 2630\pi^{\#}$ REF p 3

$A_{S.O.} = \frac{2\pi}{2}(2.0 + 4.00)\,t$

$t = .400 - .125 = .275$

$= 6\pi(.275) = 1.65\,\pi\ \text{IN}^2$

$= \frac{2630}{1.65}$ 1600 PSI

$F_{SHR} = .5\,F_t = .5(8,500) = 4,250$ psi

$M.S. = \frac{4250}{1600} - 1 = \underline{\underline{H}}$

Shear-out - 1020 Stl

$$f_s = f_{s_{MX2625}} \times \frac{t_{MX2625}}{t_{STL}} \times \frac{\Sigma D_{MX2625}}{\Sigma D_{STL}}$$

$$= 1600 \times \frac{.275}{.125} \times \frac{6.0}{(2.25 + 3.45)}$$

$$= 1600 \times 2.2 \times \frac{6.0}{5.7} = 3750$$

$F_{SH} = 35,000$ PSI

$M.S. = \frac{35,000}{3750} - 1 = H$

BENDING : STL (APPROXIMATE)

$f_b = \frac{6M}{t^2}$ CONSERVATIVE

$M = f_{s_{STL}} t .275 = 3750 t (.275) = 1060 t$ "-#/"

$= \frac{6(1060)}{.275} = \frac{6360}{.275} = 23{,}200$ PSI

$F_T = 35{,}000$ psi

$M.S. = \frac{35.0}{23.2} - 1 = \underline{\underline{.51}}$

BENDING: MX 2625 (APPROXIMATE)

$f_b = \frac{6M}{t^2}$

$M = f_{s_{MX}} t_{MX} .275 = 1600 t .275 = 440 t$ "-#/"

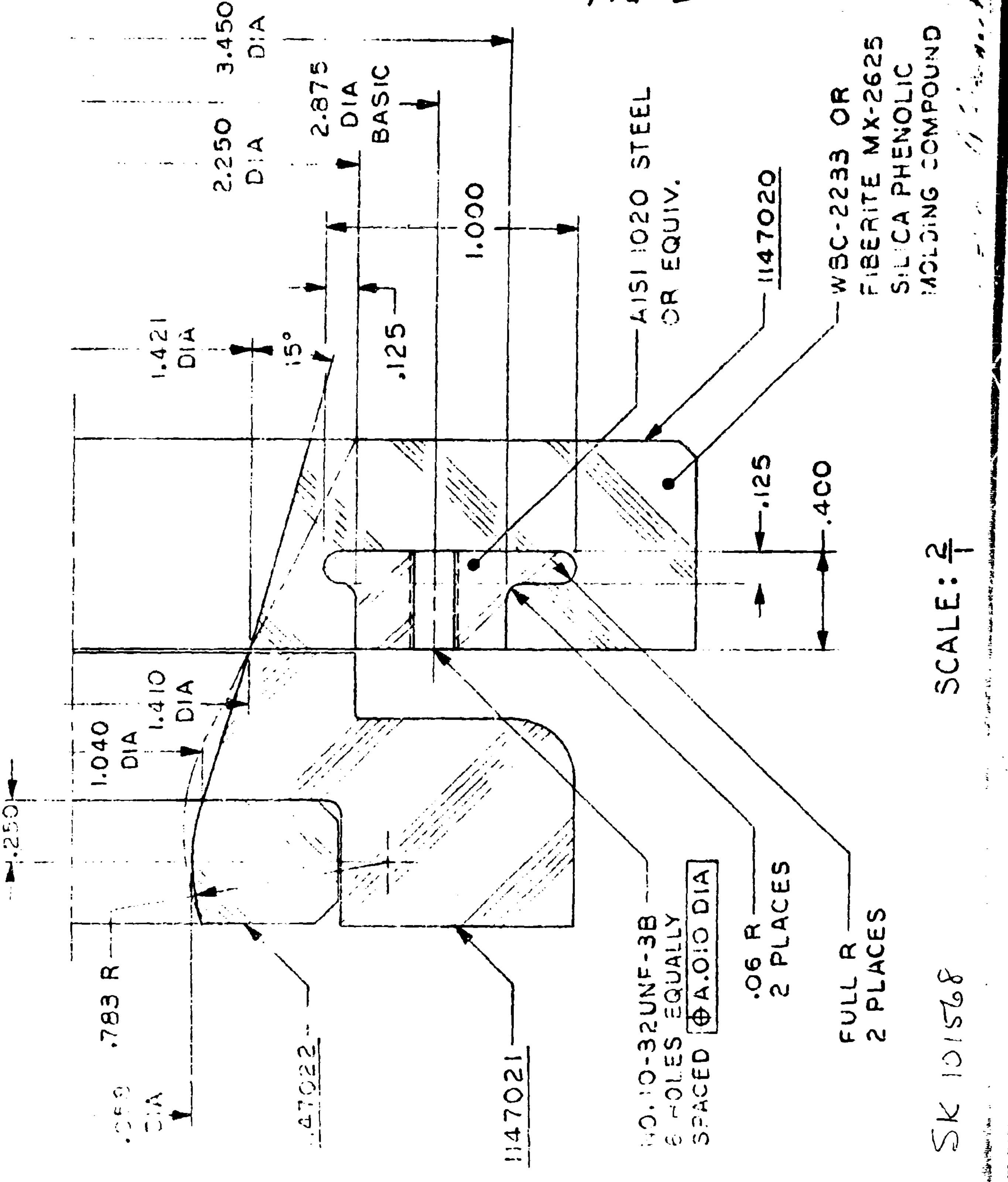
$= \frac{6(440)}{.275} = 9600$ psi

$F_T = 10{,}000$ psi

$M.S. = \frac{10{,}000}{9600} - 1 = \underline{\underline{.04}}$

B.D. 3

FIG III-19



AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS-0800-11

REPORT NO.	PAGE 3.26 OF

SUBJECT: -20 PULSE IGNITER

DATE

WORK ORDER

BY: H. EFRON

CHK. BY

DATE

LINER, IGNITER CLOSURE # 1147025 NYLON

ϵ = 70% ELONGATION per SPEC L.P.

THIS ϵ IS ADEQUATE

ENTRANCE CAP #1147023 W.B 8217 CARBON PHENOLIC

NO APPARENT PRESSURE LOADS

THROAT IGNITER #1147022 PYRO,

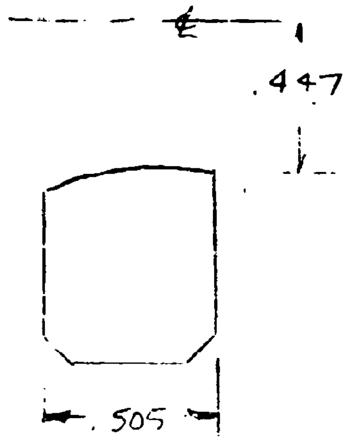


FIG III-20

GAP REQ'D FOR AXIAL THERMAL GROWTH

$\Delta l = \alpha \, \Delta T \, l$

$l = .505$

$\Delta T = 5000°F$

$\alpha = 14.0 \times 10^{-6}$ in/in-°F

$= 14 \times .505 \times 5000 \times 10^{-6} = .0353$

THIS INDICATES THAT 0.036" CLEARANCE IS REQUIRED AT INSTALLATION TO PERMIT FREE THERMAL EXPANSION OF THE PYRO

AGC8-0600-11

REPORT NO.	PAGE 3 of 7 OF
SUBJECT: 20 PULSE IGNITER	DATE
	WORK ORDER
BY: H. EFRON / CHK. BY	DATE

INSULATOR - CLOSURE DWG 1147024
WB 2237
SILICA PHENOLIC

ESTIMATED HOOP STRAIN IN STEEL CLOSURE
REF DWG 1147019

$\epsilon_{STL} = \frac{f_H}{E_{STL}} = \frac{pR}{Et}K$

$E_{STL} = 30\times10^6$ psi

$K < .76$

$= \frac{3000(4.25)(.76)10^{-6}}{.13\times30} = .0025$

$= .25\%$

ALLOWABLE STRAIN, ESTIMATE

$\epsilon_{ALL} = \frac{F_{ALL}}{E}$

$E = 3.0\times10^6$ psi

$F = 14000$ psi

$= \frac{.014}{3.0} = .00475$

$= .475\%$

$M.S. = \frac{.475}{.25} - 1 = .90$

AEROJET-GENERAL CORPORATION
SACRAMENTO · CALIFORNIA

AGCS-0800-11	REPORT NO.	PAGE 3.D.8 OF
SUBJECT: 20 PULSE IGNITER		DATE
		WORK ORDER
BY: H. ETRON	CHK. BY	DATE

FASTENER - NAS-560-3-00 HK

$P_{ALL} = 2800^{\#}$

$P = 1370^{\#}$

$$M.S. = \frac{2800}{1370} - 1 = 1.1$$

APPENDIX C

THERMAL ANALYSIS OF TWENTY-PULSE IGNITER FOR STOP/START ROCKET MOTOR

SECTION I

INTRODUCTION

The thermal analysis of the stop/start igniter was performed to determine the maximum possible temperature increase of the SCID located in the igniter membrane for various thicknesses of the membrane. To facilitate the analysis, it was assumed that the SCID temperature corresponds to the backside temperature of the membrane. The computed relationship between the maximum backside temperature increase and the membrane thickness is shown in Figure C-1. For example, this figure gives a temperature increase of 155°F for a 0.1-inch thickness. Figure C-2 shows the backside and frontside temperature responses of the membrane for three different thicknesses.

SECTION II

DISCUSSION

To adequately predict the maximum temperature of the igniter membrane, the initial procedure of the analysis was to subdivide the internal surfaces of the igniter chamber into nodal sections. Figure C-3 shows the nodal subdivisions for the case analyzed. Heating of these surfaces was assumed to be caused by convective heat transfer from the combustion products of the propellant.

The temperature responses for each nodal section were obtained from a thermal model which calculates the transient temperature response for a composite material which reacts or decomposes in depth. This is a one-dimensional, transient thermal model capable of including local surface regression, internal decomposition (charring), and transpiration of pyrolysis gases to the exposed surface.

The total heat flux incident on the membrane, assumed to be due to radiation from the chamber internal surface, is the summation of the individual contributions from the different sections. The basic radiation equation used to obtain the heat transfer between the different sections and this membrane is given below.

$$Q_i = \sum_{j=1}^{N} F_j \sigma (T_{ji}^4 - T_{mi}^4)$$

Q_i = Total incident heat flux on the membrane surface at time (i) (Btu/ft^2-sec)

F_j = Configuration factor from the membrane to the individual sections (j)

$T_{j,i}$ = Temperature of an individual section at time (i) (°R)

II, Discussion (cont.)

$T_{m,i}$ = Frontside temperature of the membrane at time Oi) (°R)

σ = Stefan-Boltzmann constant

Using this heat flux data in the previous mentioned thermal model, the temperature responses for the various thicknesses of the membrane were determined as shown in Figure C-2.

This particular configuration (Figure C-3) was selected for analysis because it was estimated that it represented the highest heat flux condition. The basis for this estimation is illustrated by examination of Figure C-4 which shows the maximum temperature response of a typical sidewall for approximately 12 continuous cycles. Also, the heat flux (Q_i) in the above equation is estimated to be maximum because of the relative importance of both the configuration factors (F_j) for the various axial membrane locations and temperatures of each nodal section.

Some of the important assumptions made in this analysis are listed below:

Igniter Pulse Duration	0.15 second
Motor Pulse Duration	1.5 seconds
Chamber Pressure	2000 psia
Propellant	ANP-3316
Flame Temperature	6048°F

Additional assumptions were: (1) all surface emissivities were unity; (2) combustion products or gas were transparent to thermal radiation during the off-periods; (3) radiation heat fluxes were diffuse.

II, Discussion (cont.)

Also, the thermal properties and kinetic constants of three materials and the propellant thermal properties were required for this analysis. The materials were nylon, V-4010, and RTV-60. Adequate data were obtained for V-4010 and nylon. The thermal properties used for the propellant were representative of a typical propellant. However, the only property determined for RTV-60 was the thermal conductivity at a specific temperature. The other required properties were based on the properties of similar materials. For example, the product of specific heat and density is equal to approximately 35 Btu/°F-ft^3 in the desirable temperature range. Thus, for a typical value of 90 lb/ft^3 for the density, the specific heat can be determined.

The thermal properties and kinetic constants used in this analysis for the different materials are listed below.

	Thermal Properties			Kinetic Constants		
	Thermal Conductivity (Btu/ft-sec-°F)	Specific Heat (Btu/lb-°F)	Density (lbm/ft^3)	Frequency Factor (lbm/sec)	E/R (°R)	Order of Reaction
Nylon	0.00004	0.40	71.0	1.85×10^{13}	47,100	1.0
V-4010	0.000036	0.45	68.2	1.252×10^{3}	14,660	1.219
RTV-60	0.00005	0.39	90.0	5.31×10^{10}	39,400	1.0
Propellant	0.00007	0.3	110.0	-	-	-

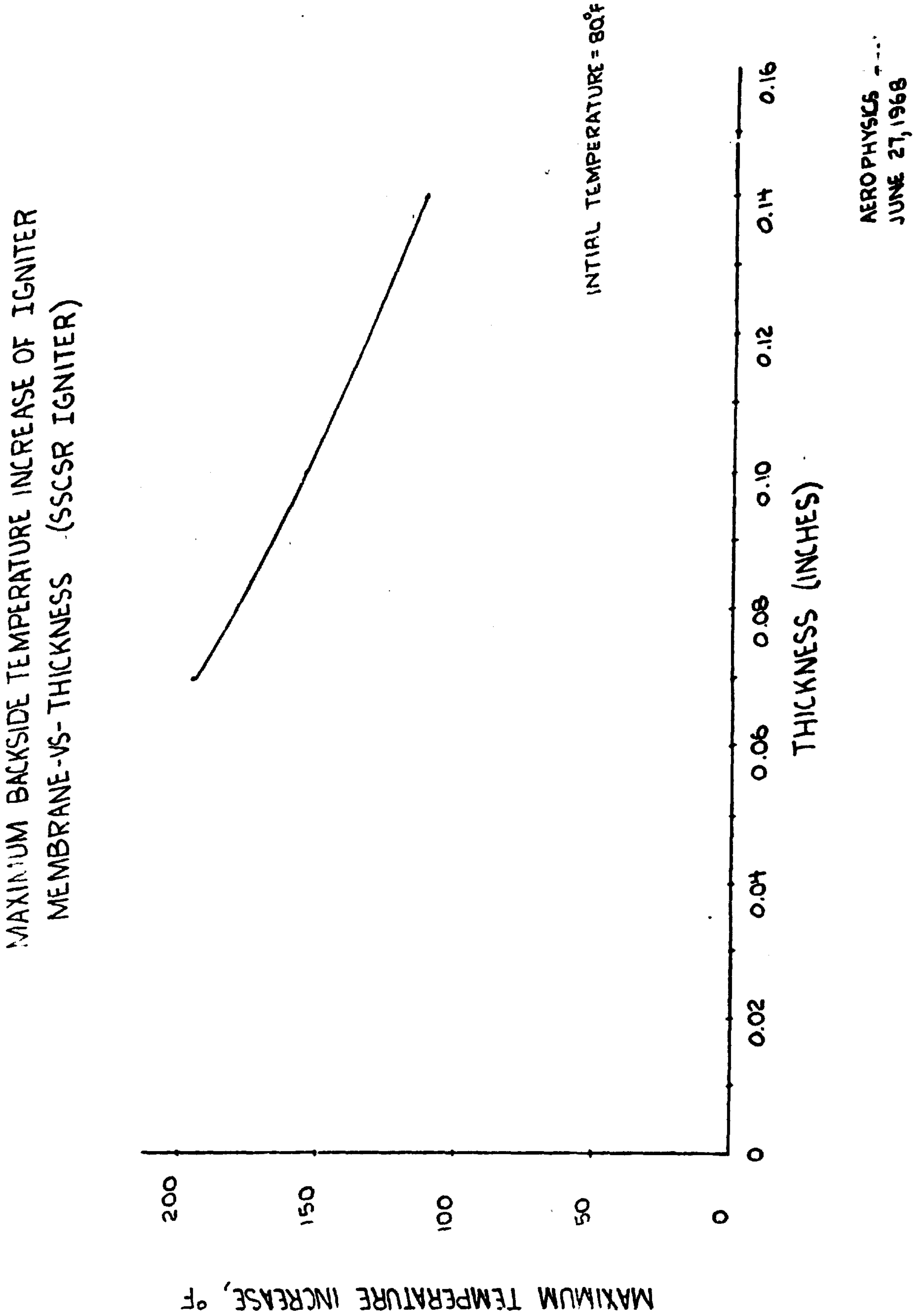


Figure C-1

Preceding Page Blank

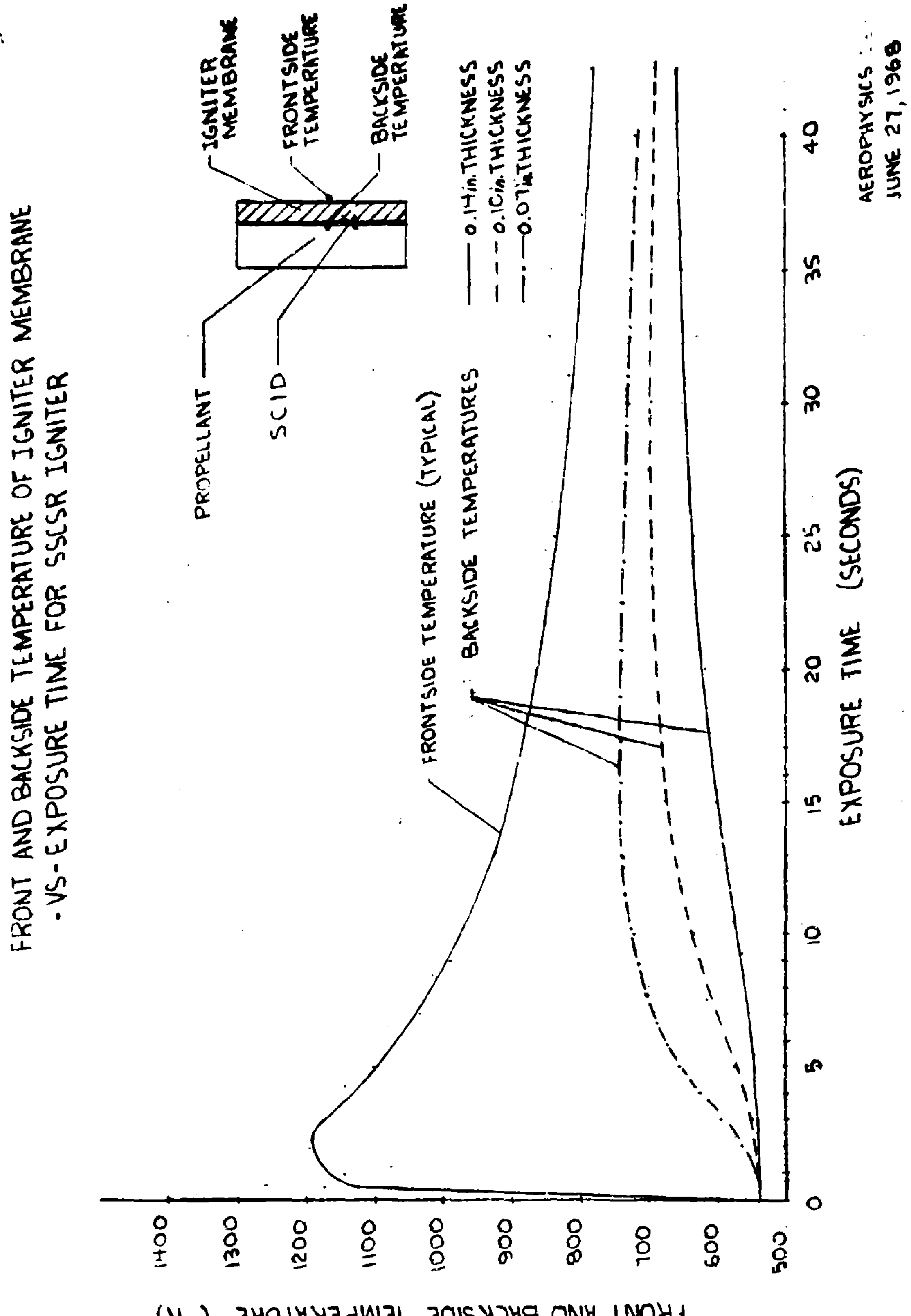
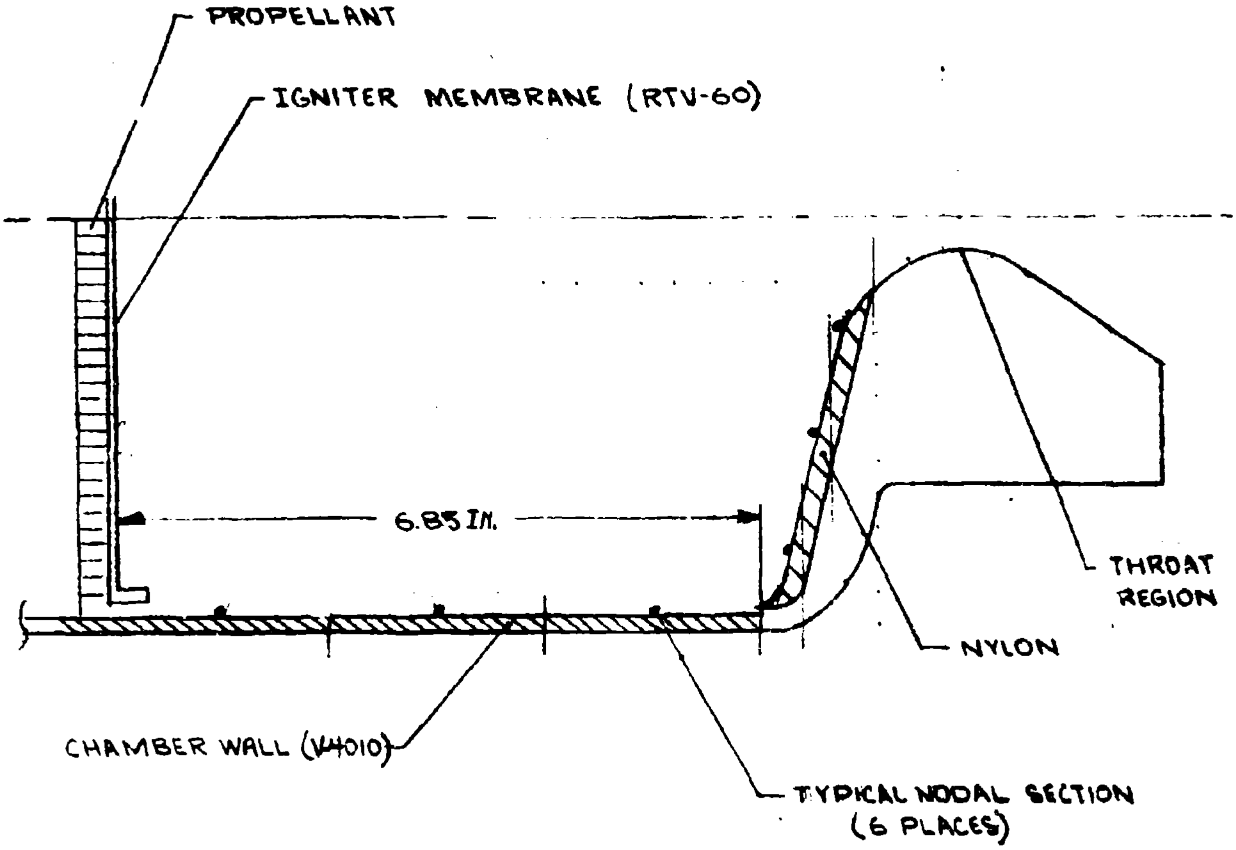

FRONT AND BACKSIDE TEMPERATURE OF IGNITER MEMBRANE
-VS- EXPOSURE TIME FOR SSCSR IGNITER
IGNITER MEMBRANE
FRONTSIDE TEMPERATURE
BACKSIDE TEMPERATURE
PROPELLANT
SCID
0.14in. THICKNESS
0.10in. THICKNESS
0.07in. THICKNESS
FRONTSIDE TEMPERATURE (TYPICAL)
BACKSIDE TEMPERATURES
AEROPHYSICS
JUNE 27, 1968
FRONT AND BACKSIDE TEMPERATURE (°R)
1400
1300
1200
1100
1000
900
800
700
600
500
0
5
10
15
20
25
30
35
40
EXPOSURE TIME (SECONDS)

Figure C-2



LOCATIONS OF NODAL SECTIONS FOR THE SSCSR IGNITER THERMAL ANALYSIS

Figure C-3

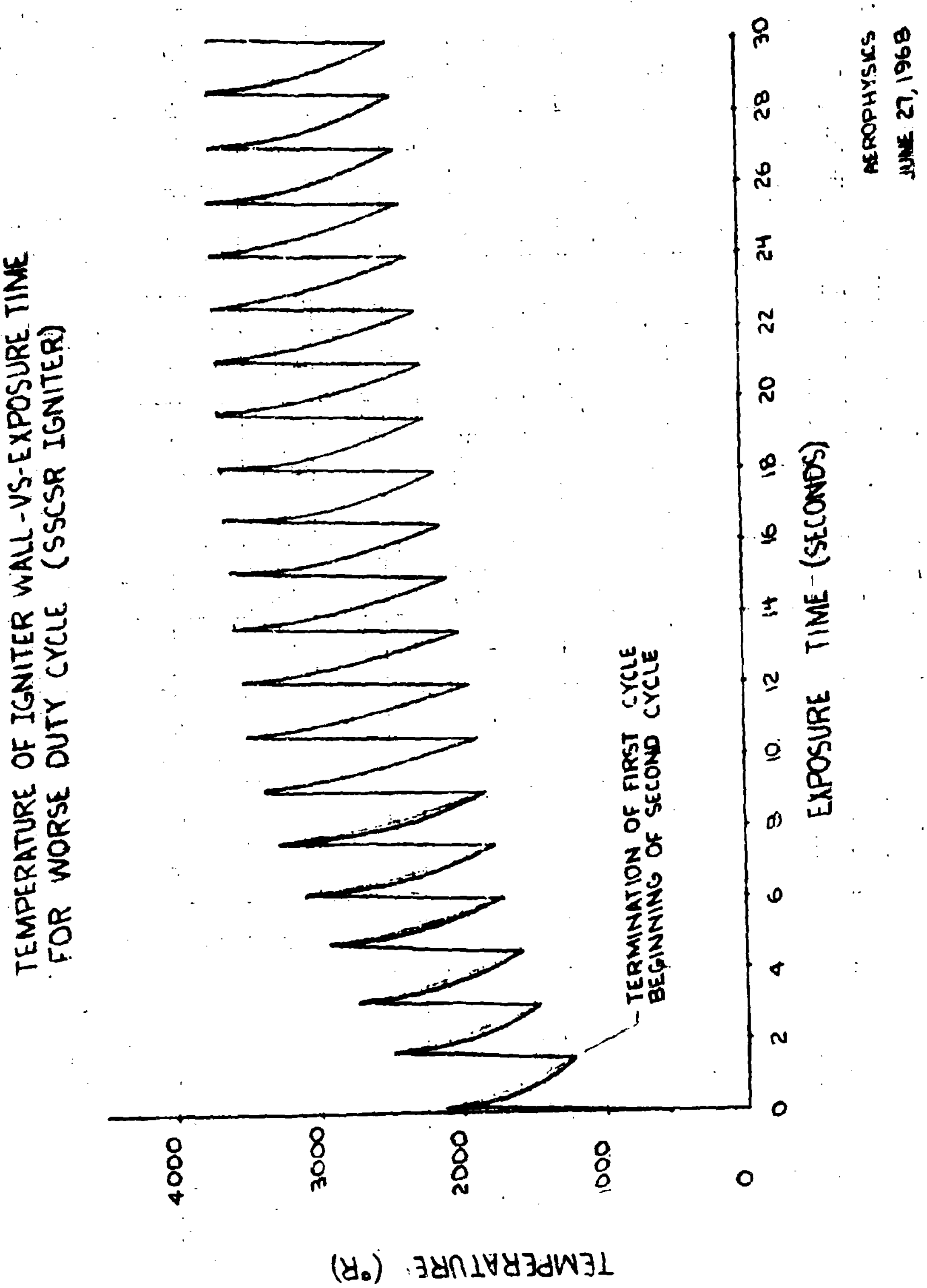

TEMPERATURE OF IGNITER WALL-VS-EXPOSURE TIME
FOR WORSE DUTY CYCLE (SSCSR IGNITER)
TERMINATION OF FIRST CYCLE
BEGINNING OF SECOND CYCLE
TEMPERATURE (°R)
0
1000
2000
3000
4000
EXPOSURE TIME (SECONDS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
AEROPHYSICS
JUNE 27, 1968

Figure C-4

APPENDIX D

PINTLE THERMAL ANALYSIS FOR SSCR

Thermal analyses were performed on all components of the Stop/Start nozzle. The pintle and pintle housing, because of their severe thermal environment, were thoroughly analyzed to determine the thermal profiles associated with stop/start duty cycle heating.

The particular configuration analyzed is depicted in Figures Appendix D-I and -II. Due to axial variation in local surface heat fluxes and the utilization of dissimilar materials, the heat conduction paths within the pintle was two-dimensional (axial and radial). As a result, all predicted thermal data obtained for the pintle and housing configuration were obtained by use of AGC's "General Thermal Analyzer" computer program. This program considers any given configuration as a series of small elements or nodes. Each node thus becomes part of an analogous electrical network wherein heat capacity and volume define the relative electrical capacity while the thermal conductivity and path length determine electrical resistance. In addition to the conduction network, the program is capable of computing special functions at each time step. For example, variable thermal properties were included by varying resistance and/or capacitance as a function of temperature. Also, resistances which describe heat flow paths between the pintle and pintle housing were varied by a switching technique to duplicate the movement of heated portions of pintle into the cooler regions of the housing. In this manner, a continuous thermal analysis of any particular duty cycle was obtained without repeatedly stopping and starting the analysis after each firing or cooling period.

Thermal analyses results obtained for various duty cycles using the techniques outlined are provided in the following figures. These data are presented in terms of predicted temperature histories for the arbitrarily

chosen nodes indicated in Figures Appendix D-I and -II. The various duty cycles investigated were:

Figure Number	No. of Pulses	Pulse on Time, Sec	Pulse off Time, Sec	Pintle Material
III-1 thru 5	1	26	474	(Backup) MX 4926
IV-1 thru 6	1	26	474	All AG Carb 101
V-1 thru 5	3	10	30	"
VI-1 thru 5	24	1	30	"
VII-1 thru 6	3	10	1	"
VIII-1 thru 6	24	1	1	"
IX-1 thru 6	27	1	10	"
X - 1 thru 6	3	10	10	"

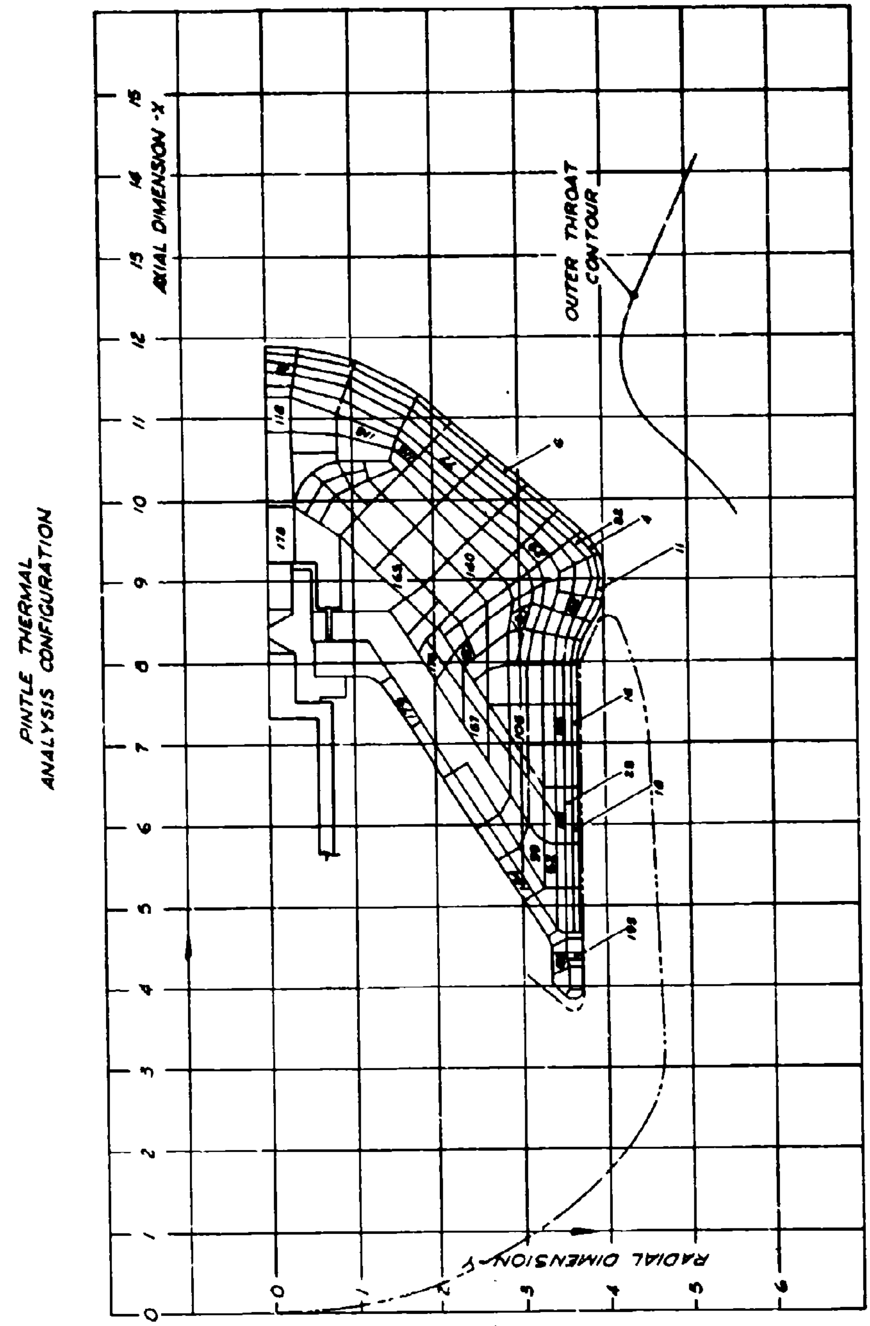

PINTLE THERMAL
ANALYSIS CONFIGURATION
AXIAL DIMENSION -X
RADIAL DIMENSION-Y
OUTER THROAT
CONTOUR

Fig. App. D-1

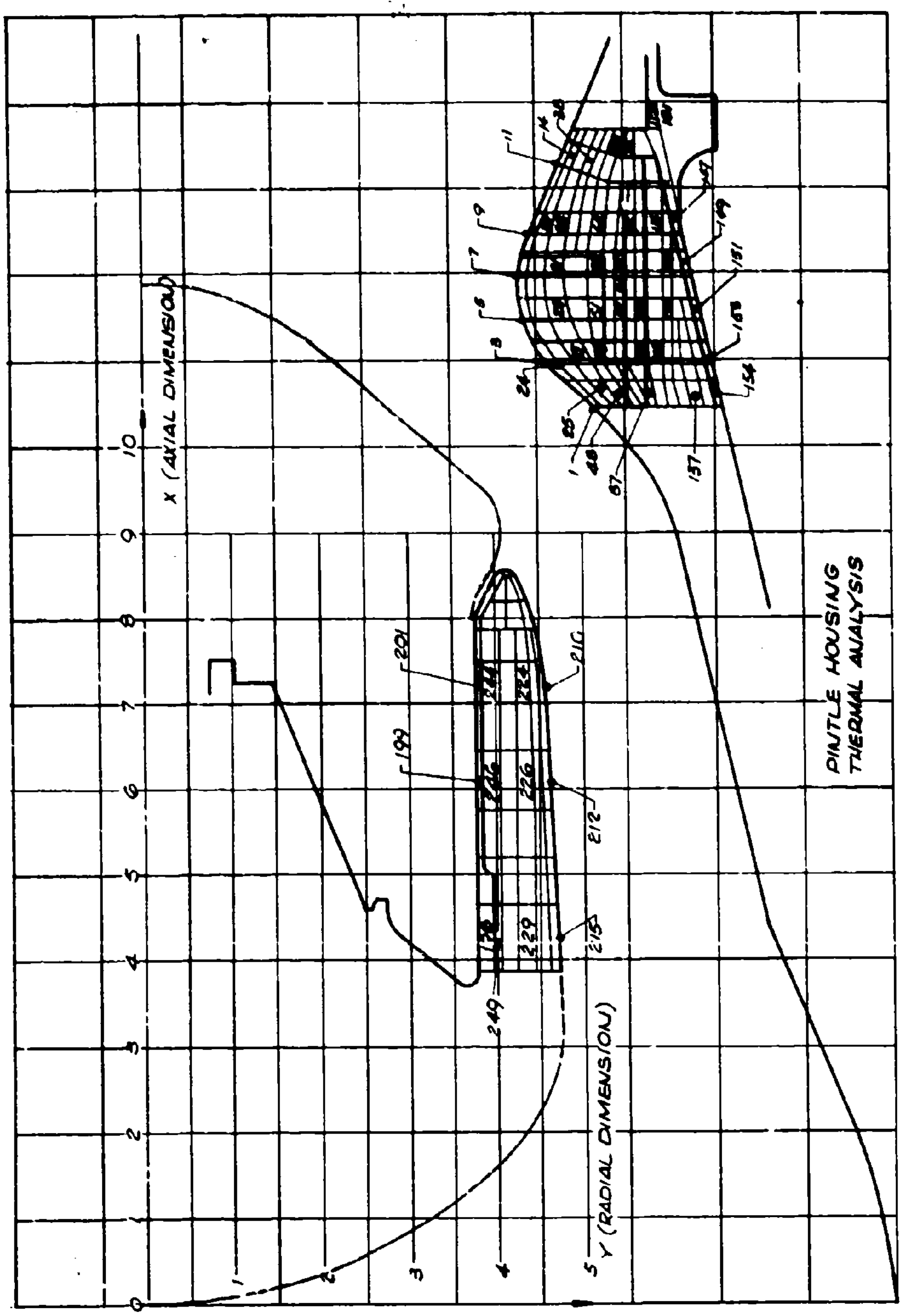

PINTLE HOUSING
THERMAL ANALYSIS
X (AXIAL DIMENSION)
Y (RADIAL DIMENSION)

Fig. App. D-2

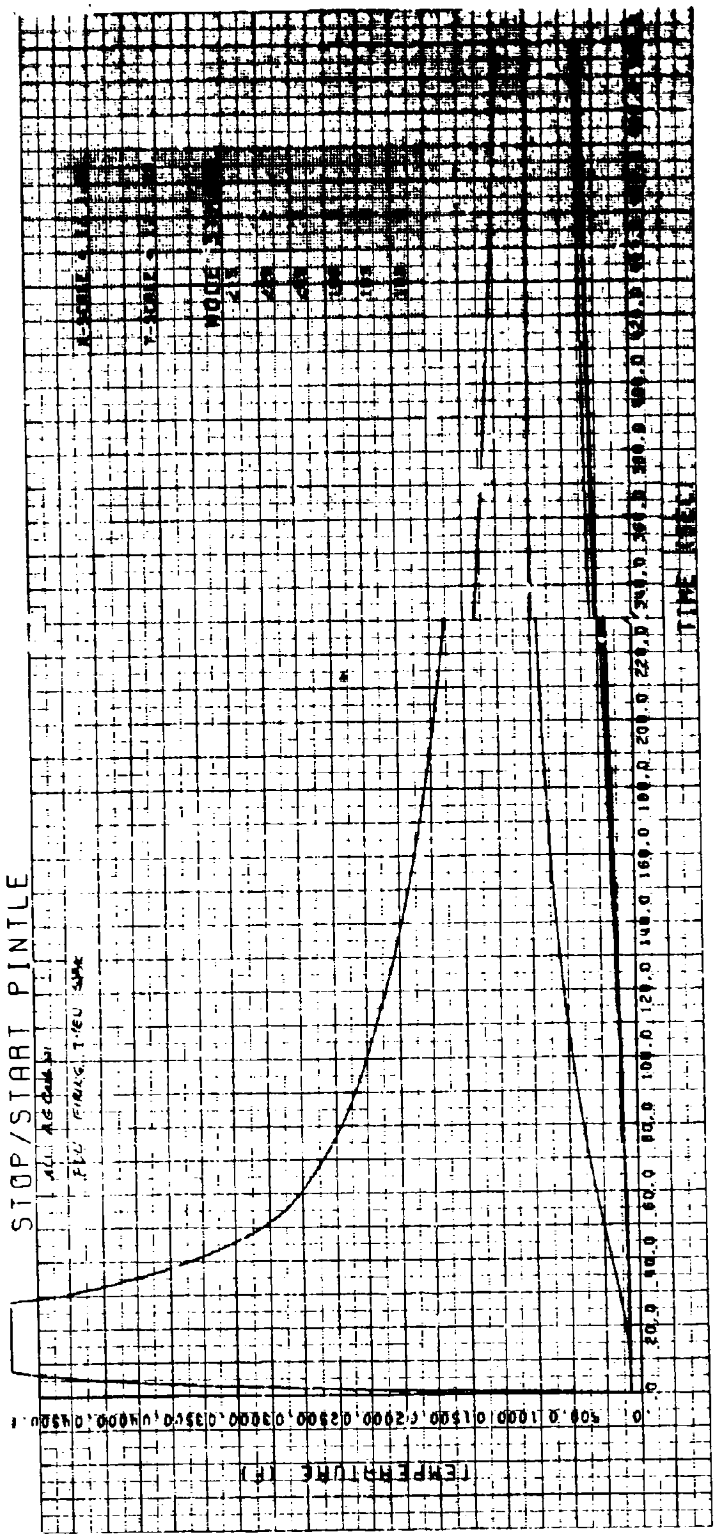


Figure III-1

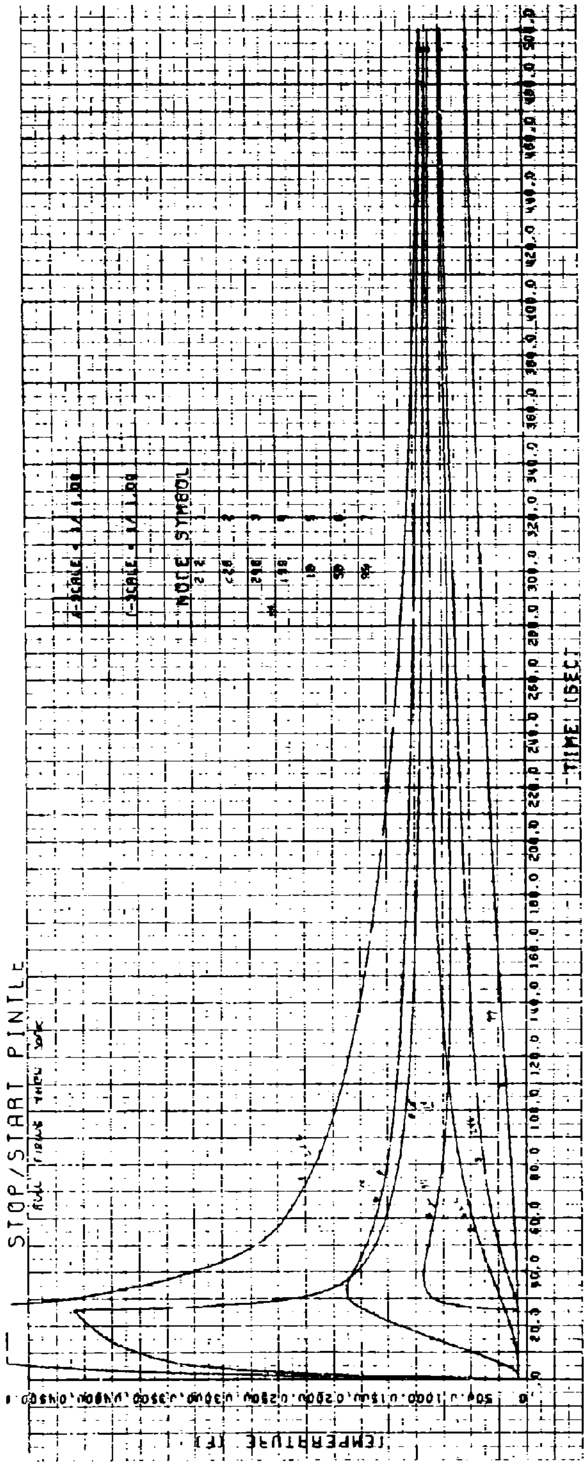


Figure III-2

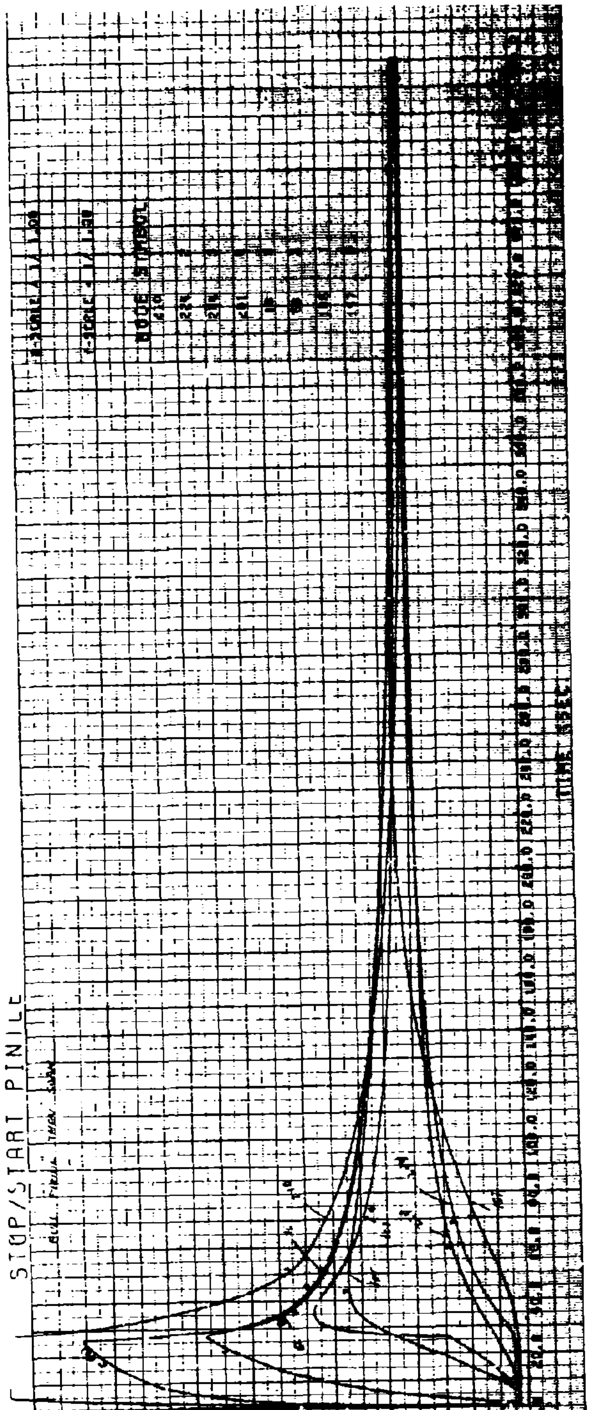


Figure III-3

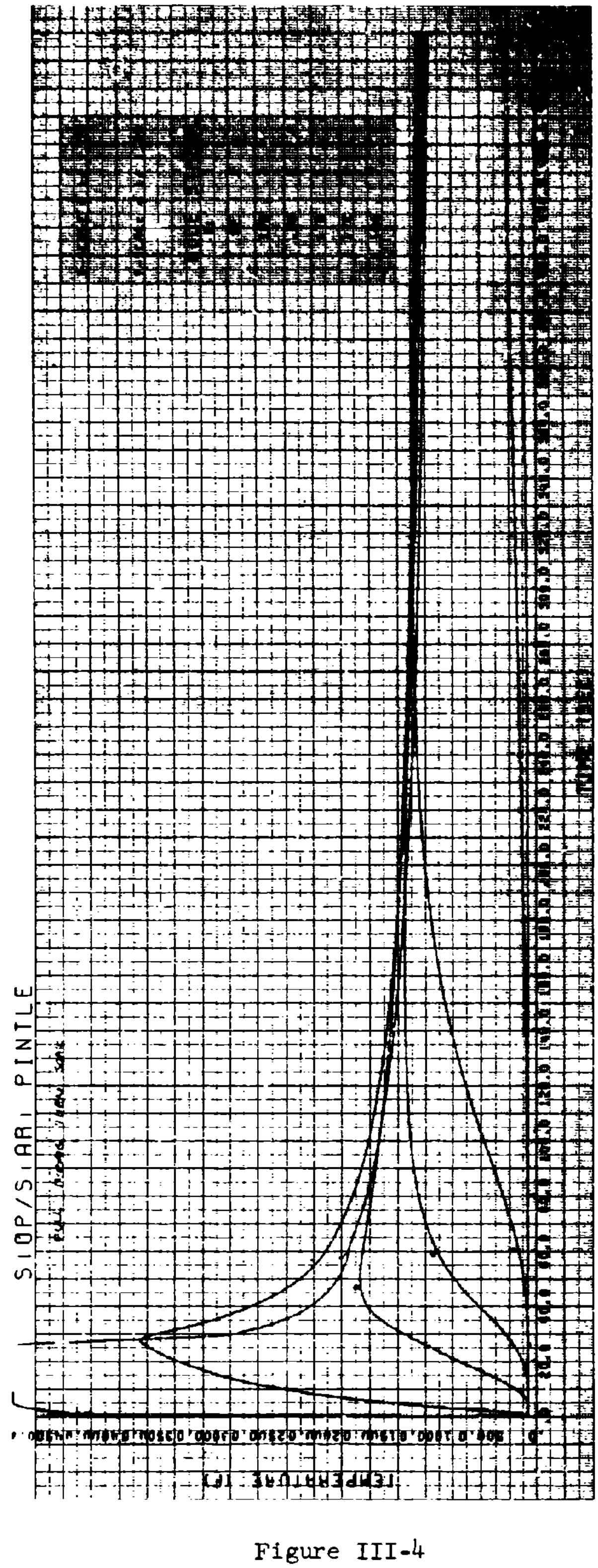


Figure III-4

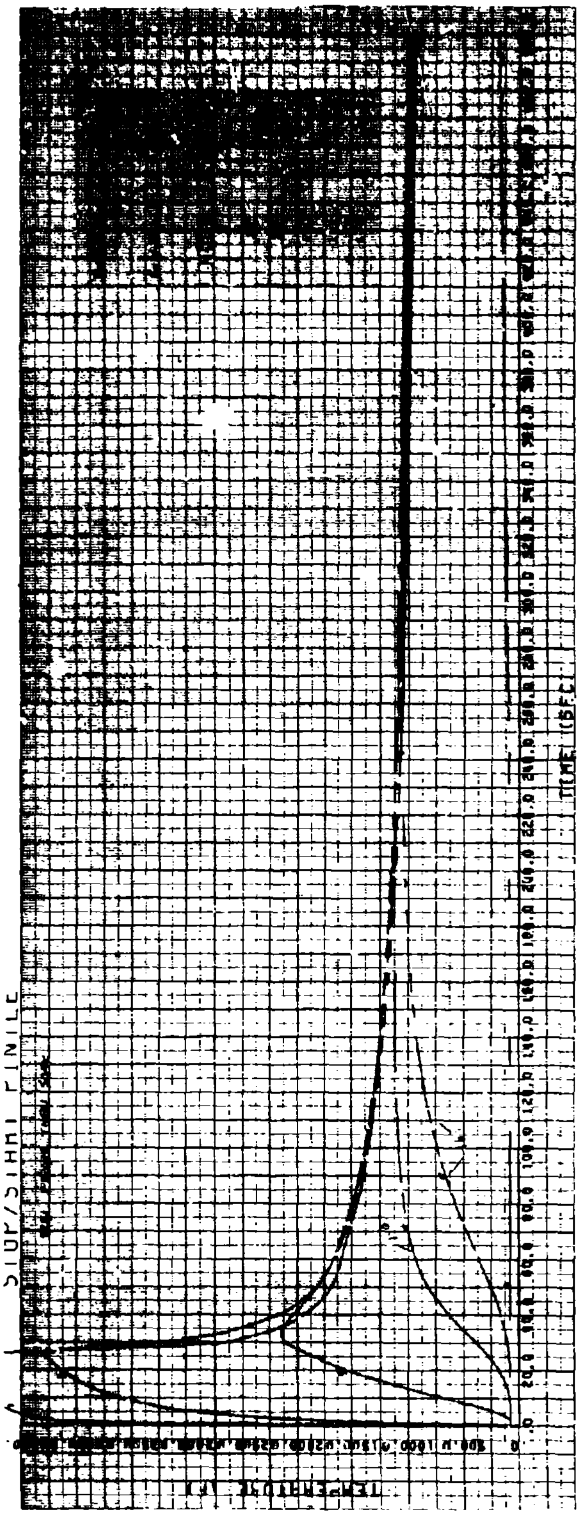


Figure III-5

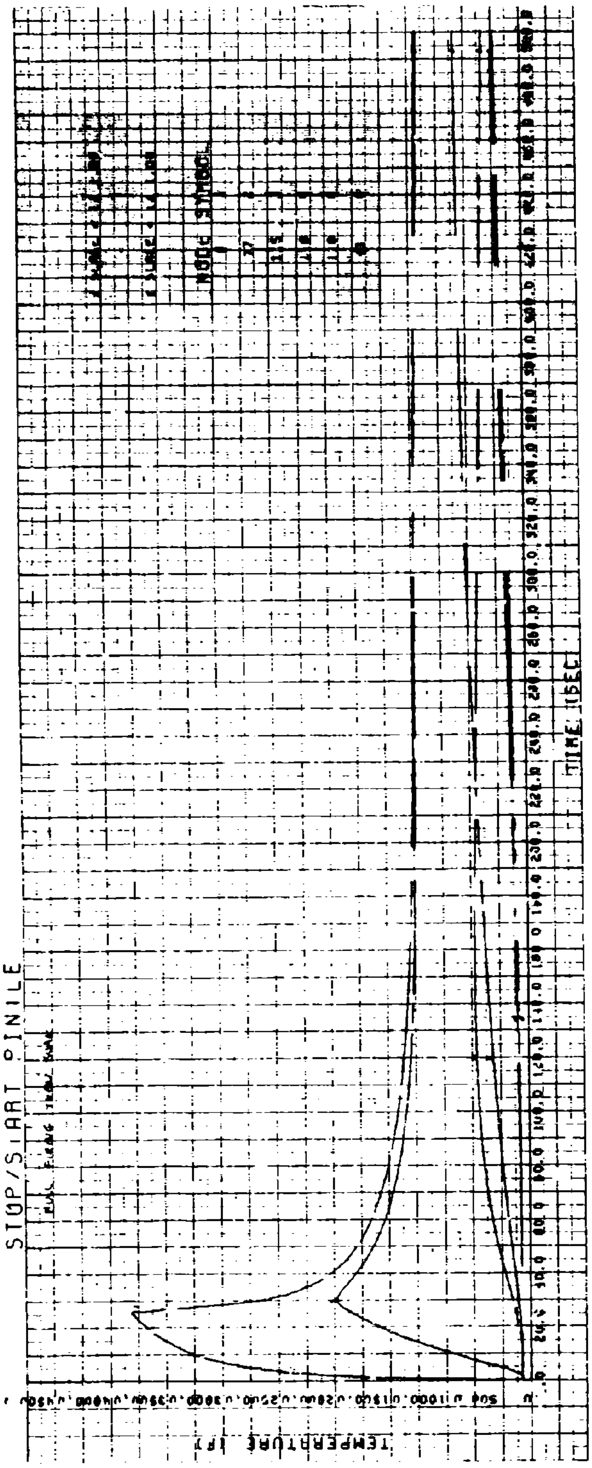


Figure III-6

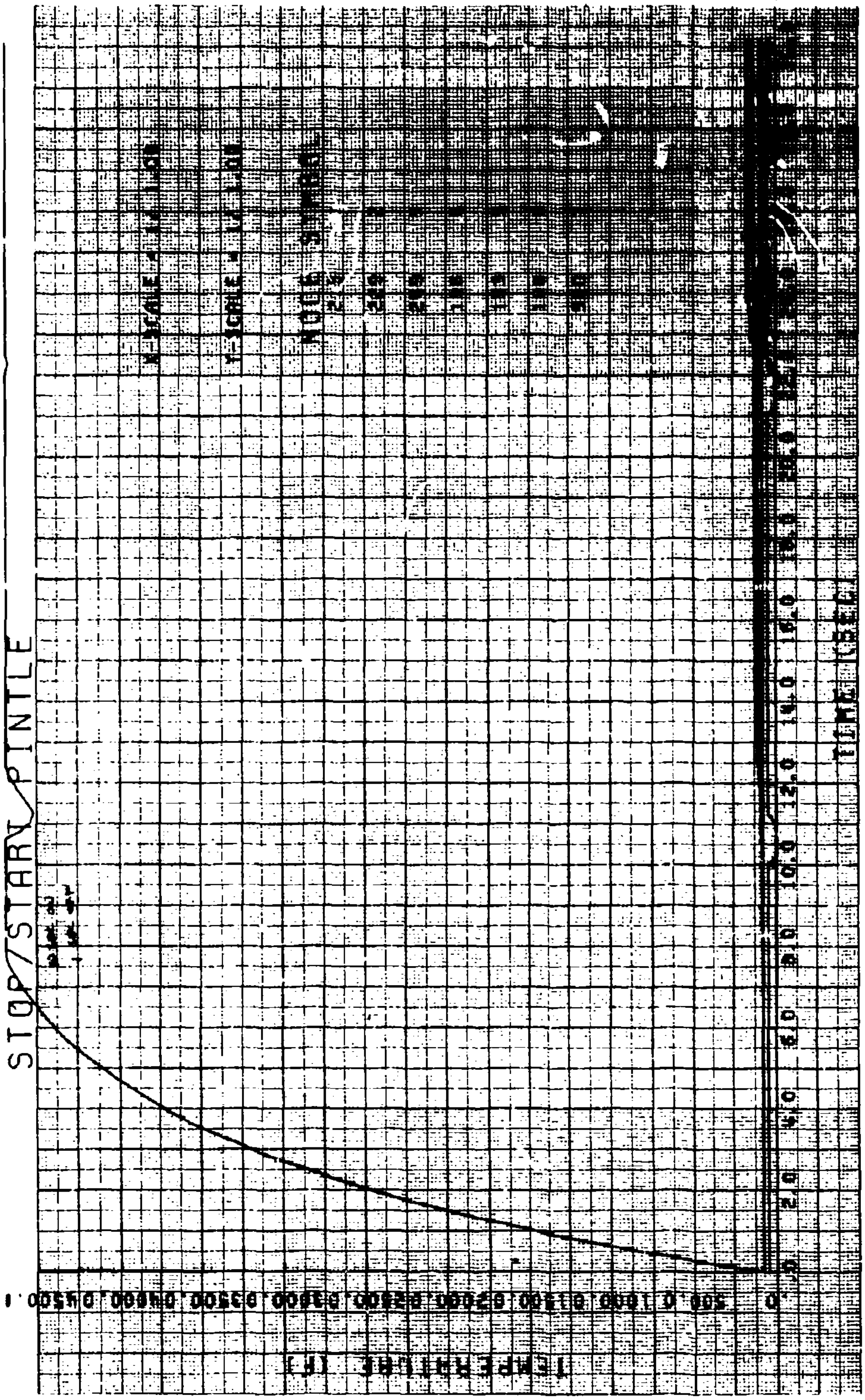


Figure IV-1

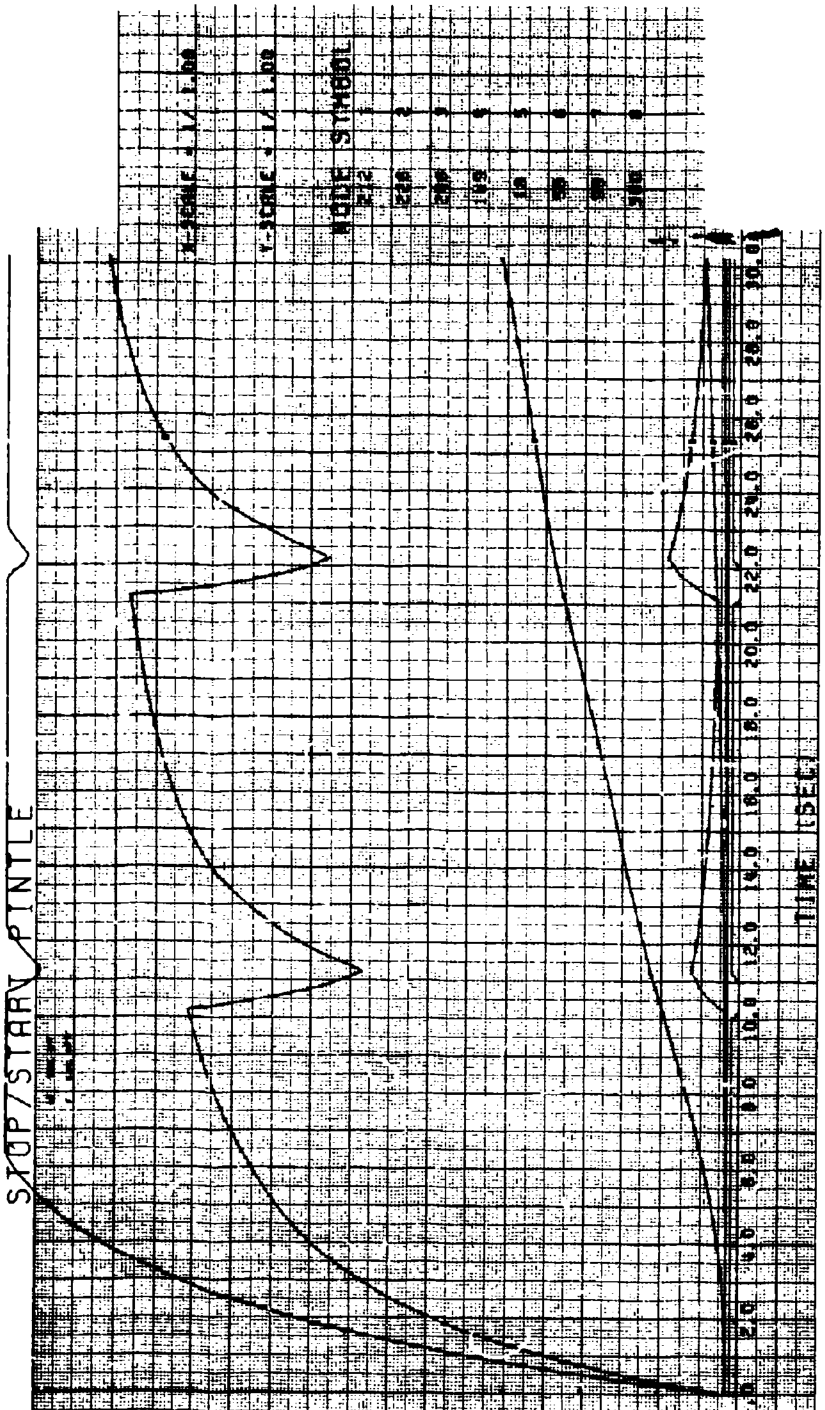


Figure IV-2

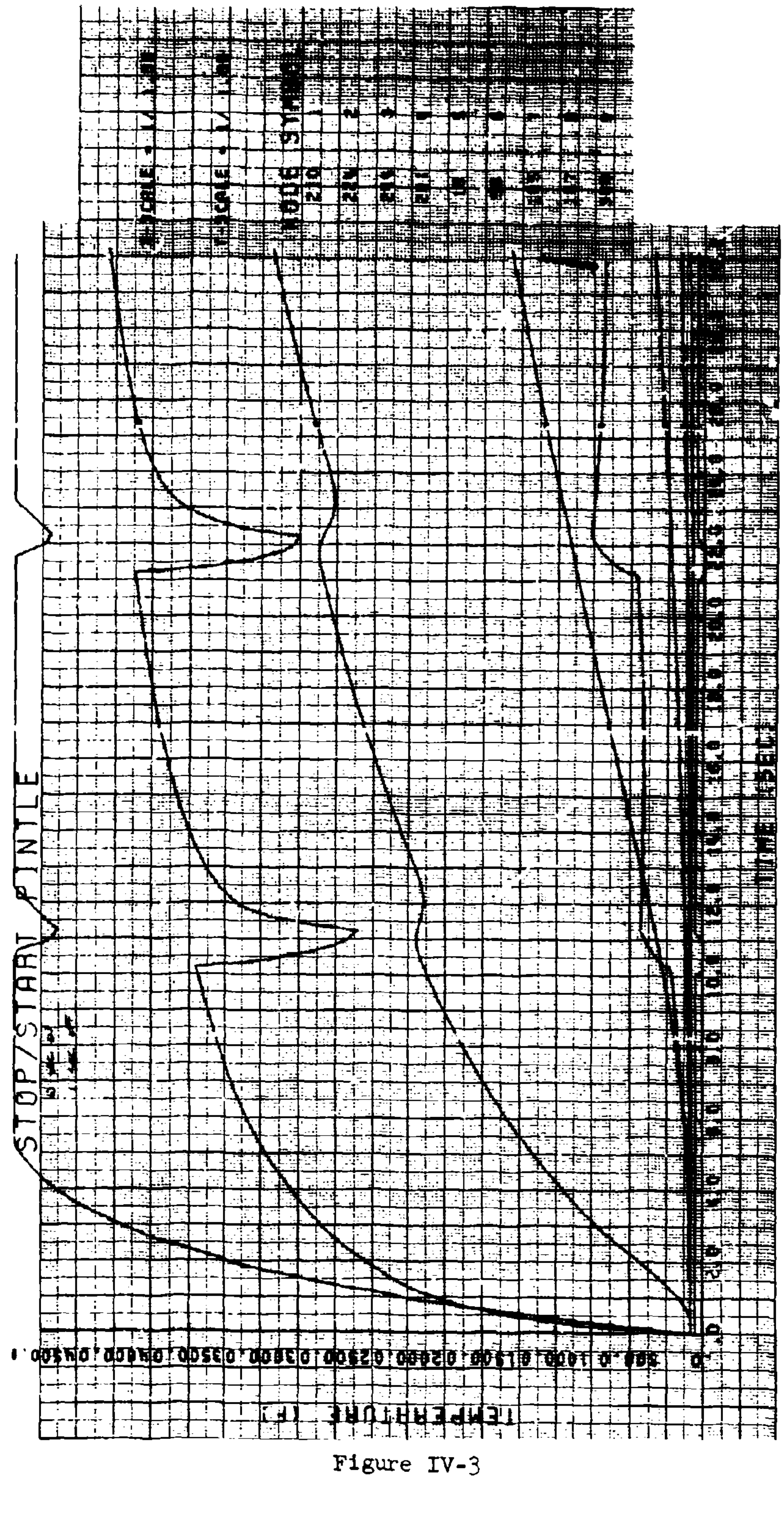


Figure IV-3

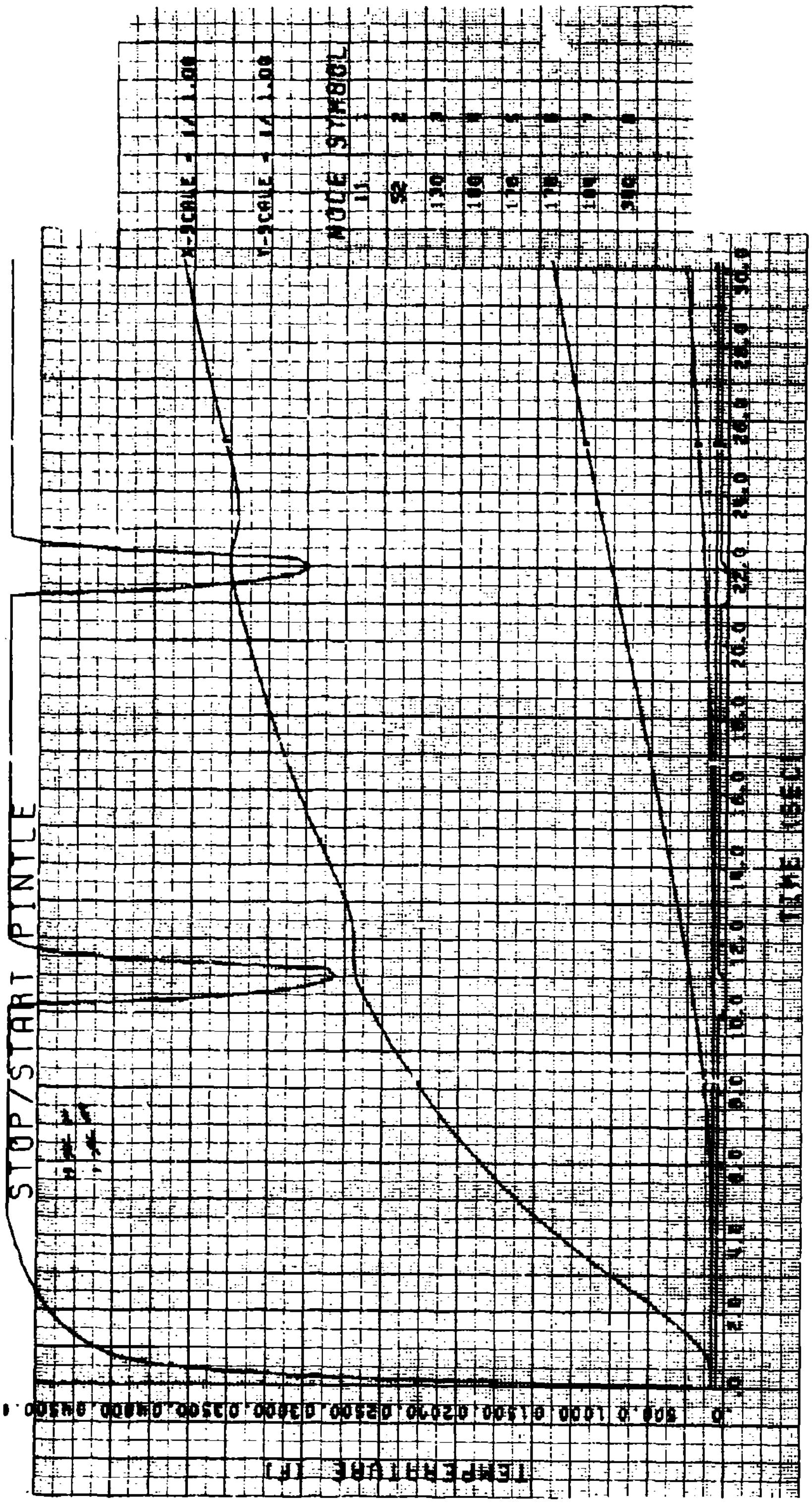


Figure IV-4

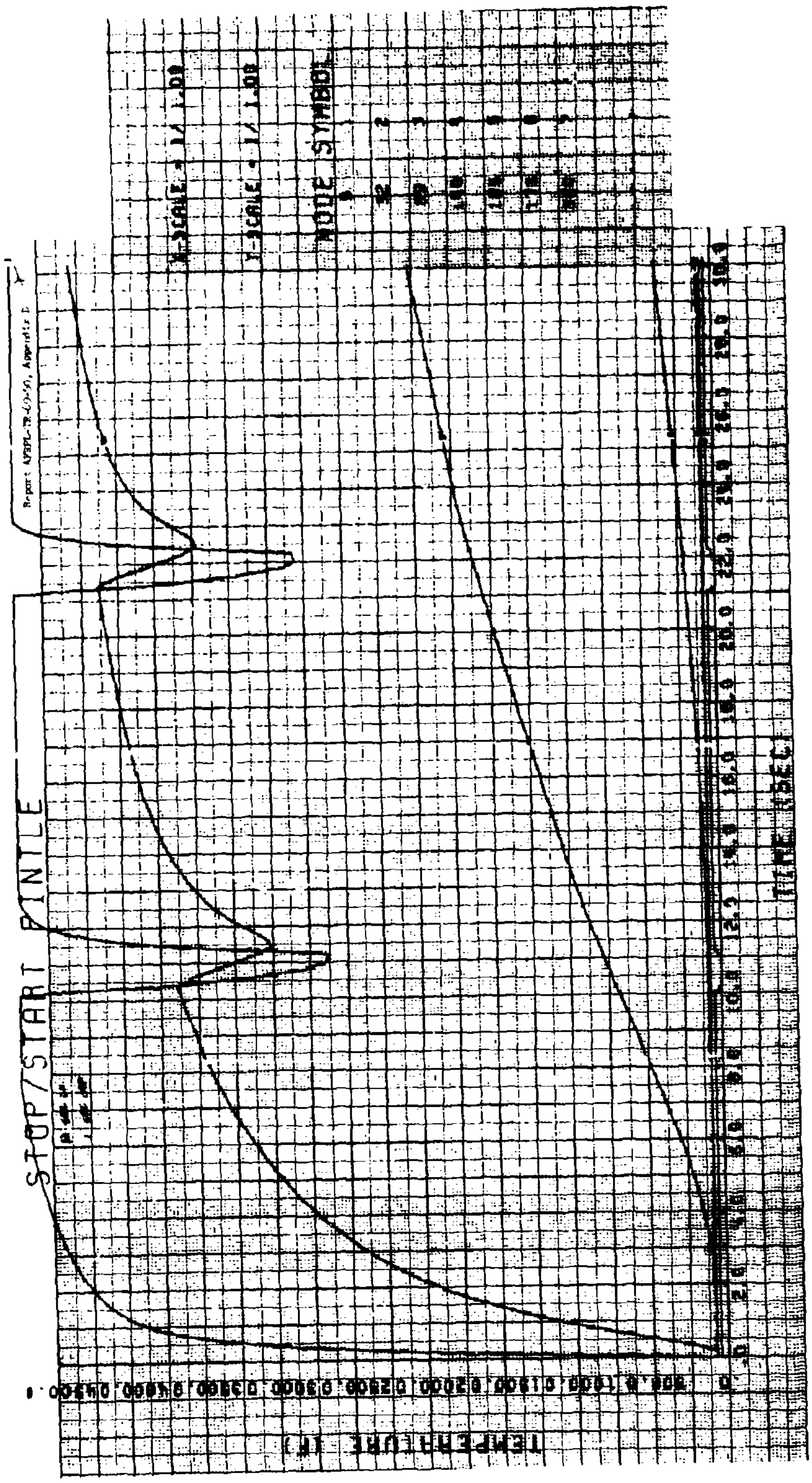


Figure IV-5

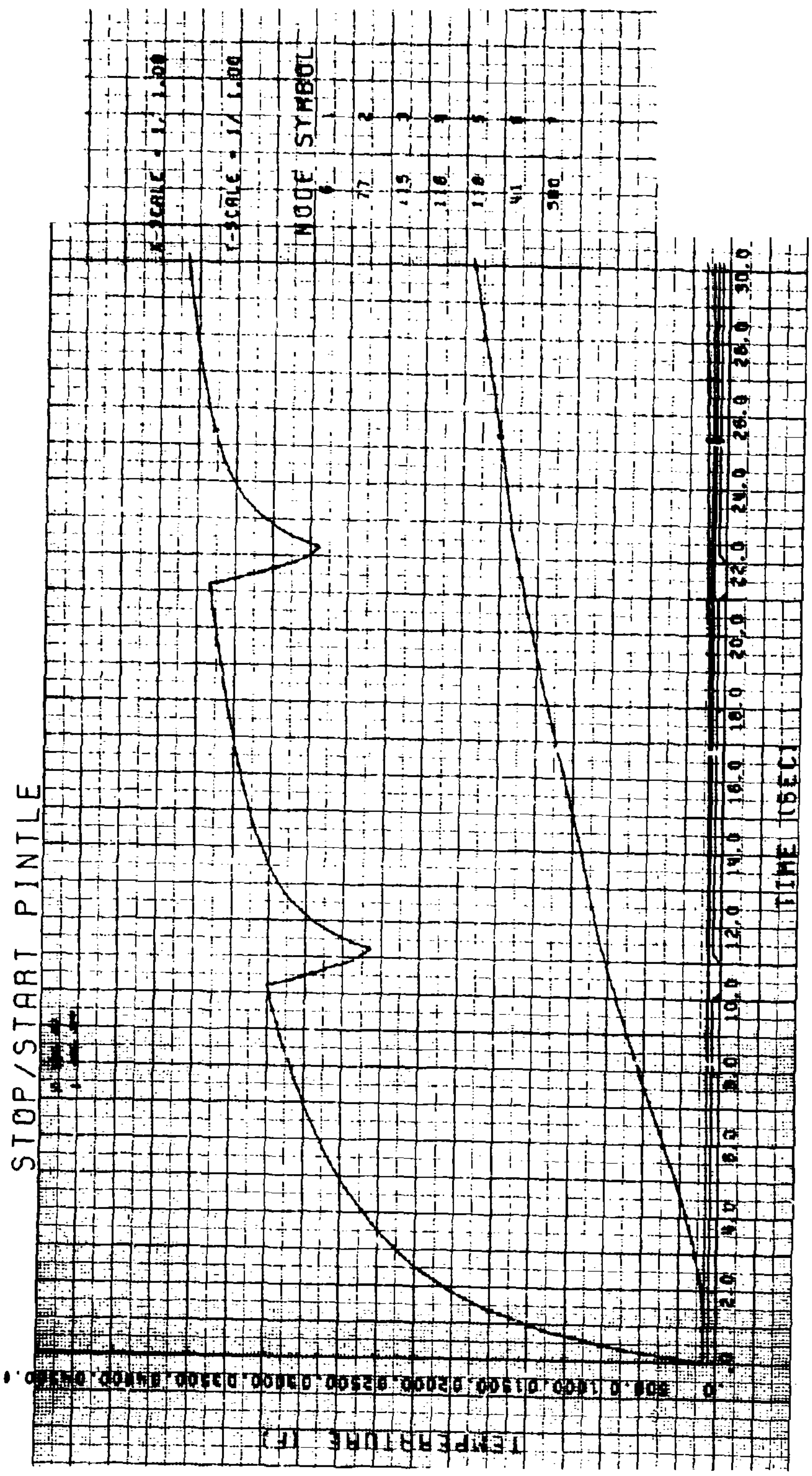


Figure IV-6

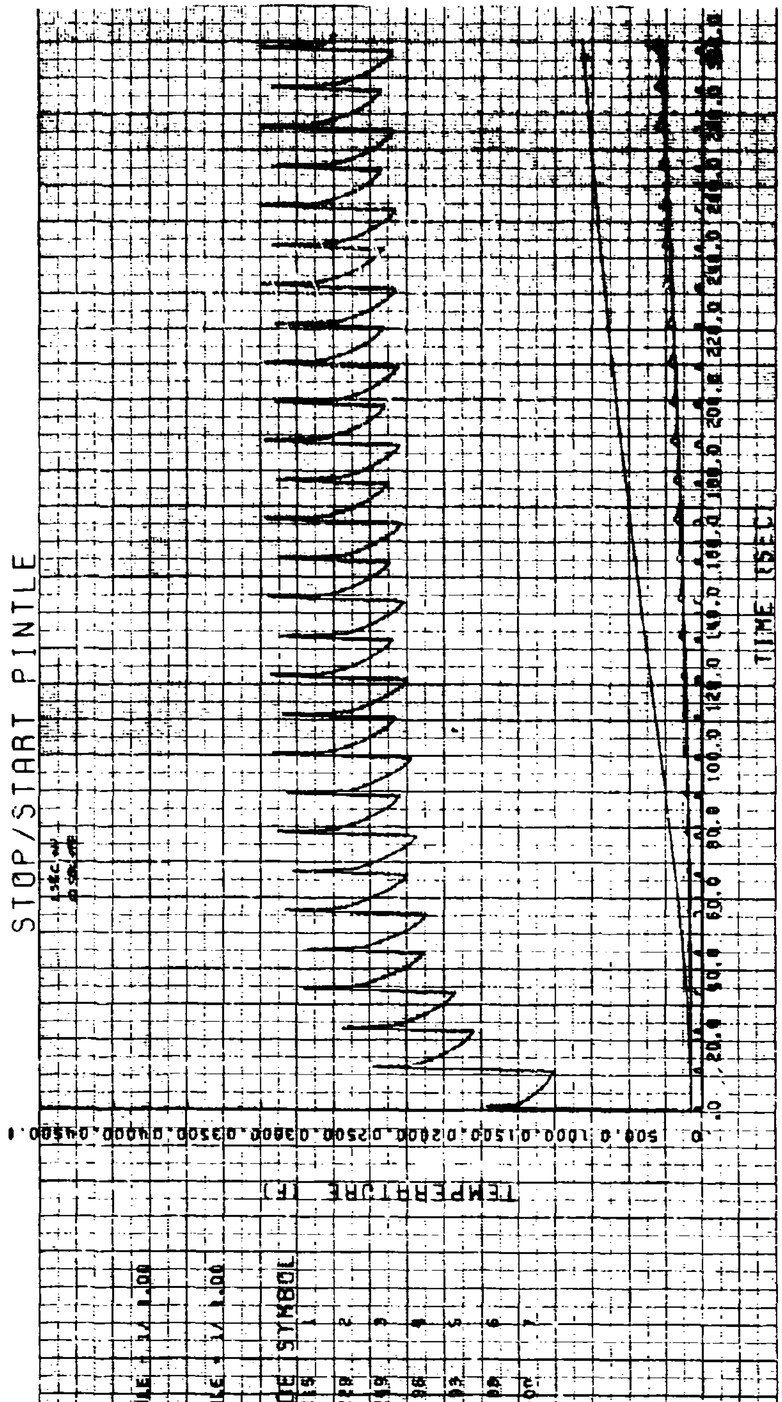


Figure V-1

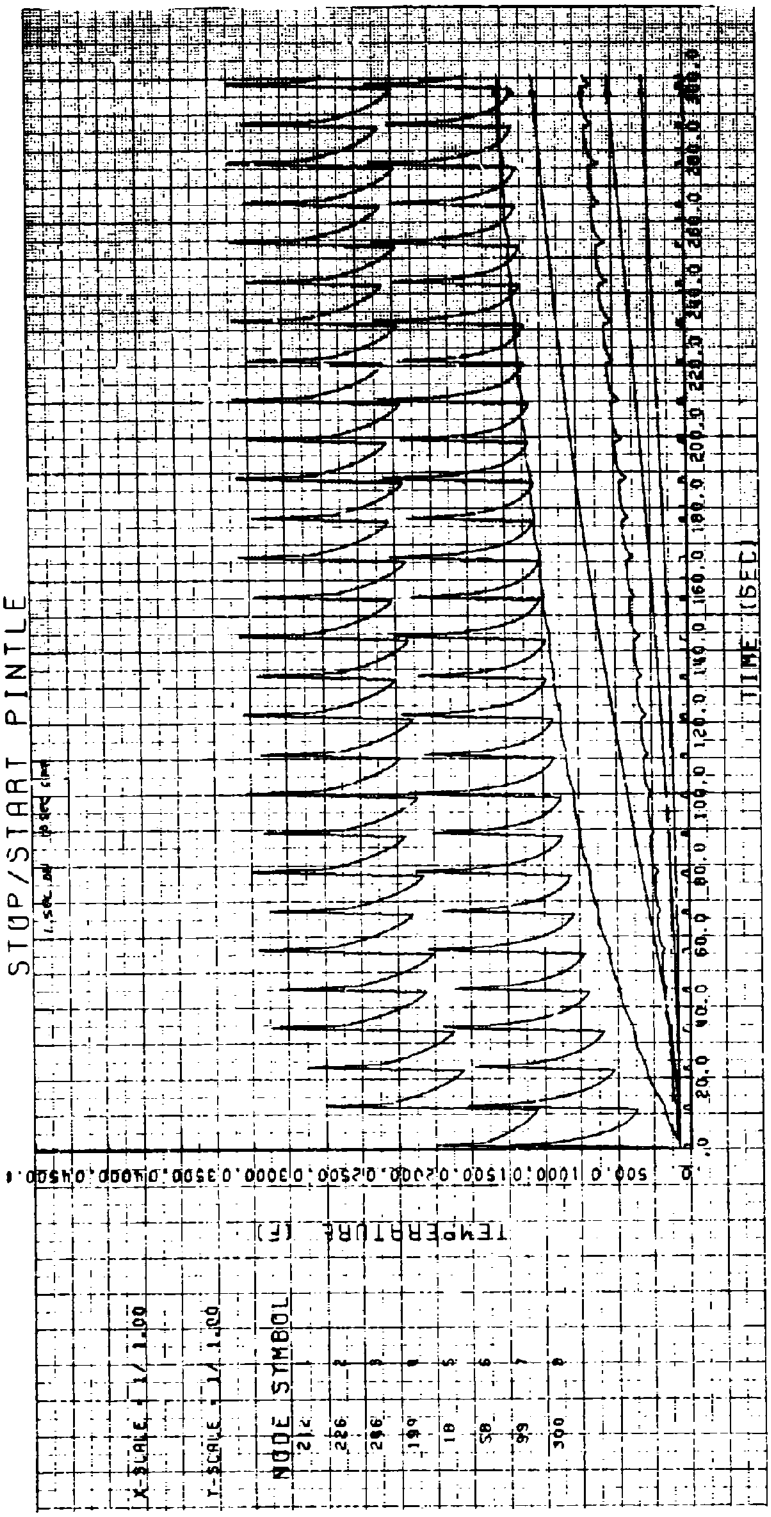

STOP/START PINTLE
TIME (SEC)
TEMPERATURE (F)
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL
212
226
296
199
18
58
99
300

Figure V-2

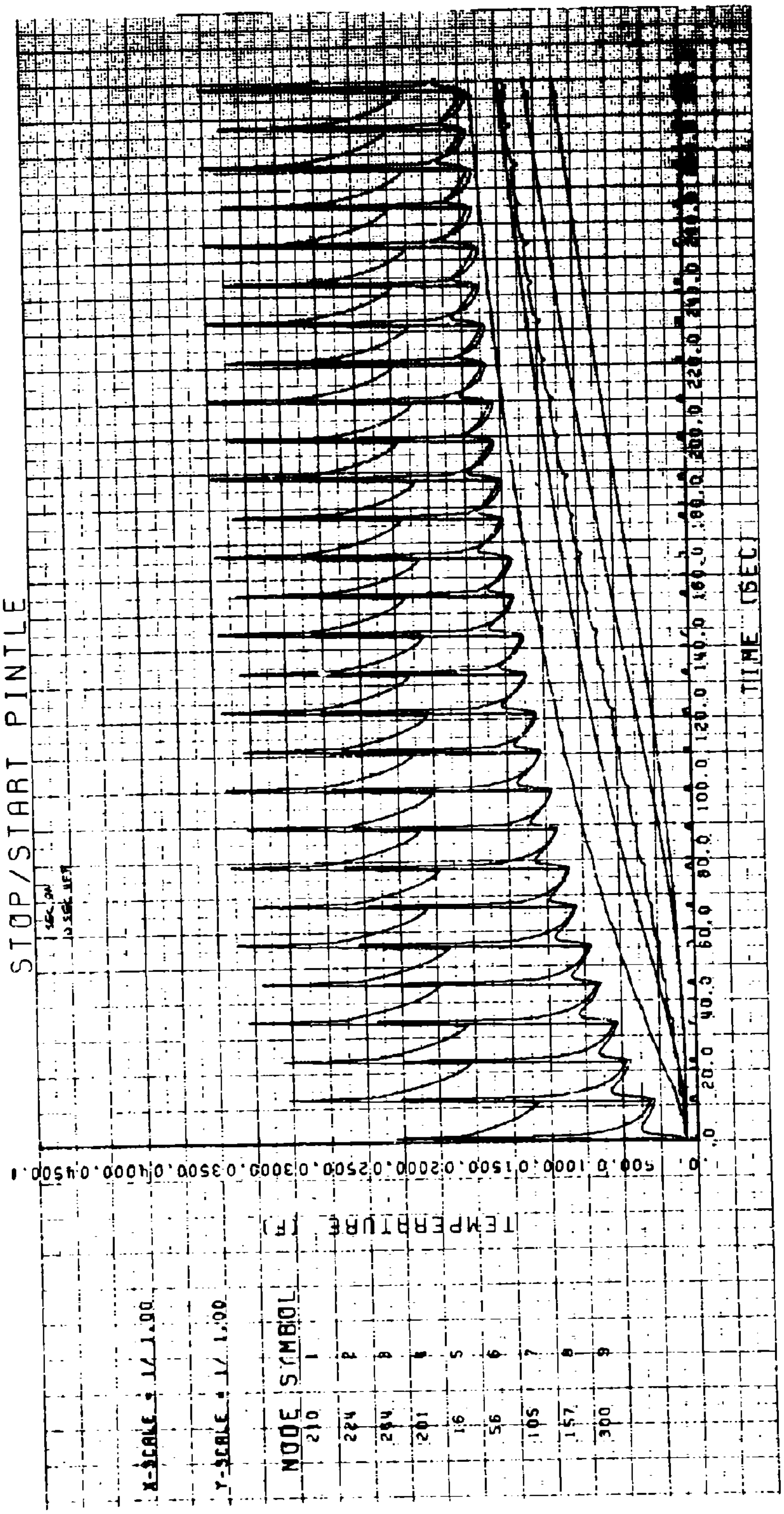

STOP/START PINTLE
TIME (SEC)
TEMPERATURE (F)
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL
210 1
224 2
284 3
201 4
16 5
56 6
105 7
157 8
300 9

Figure V-3

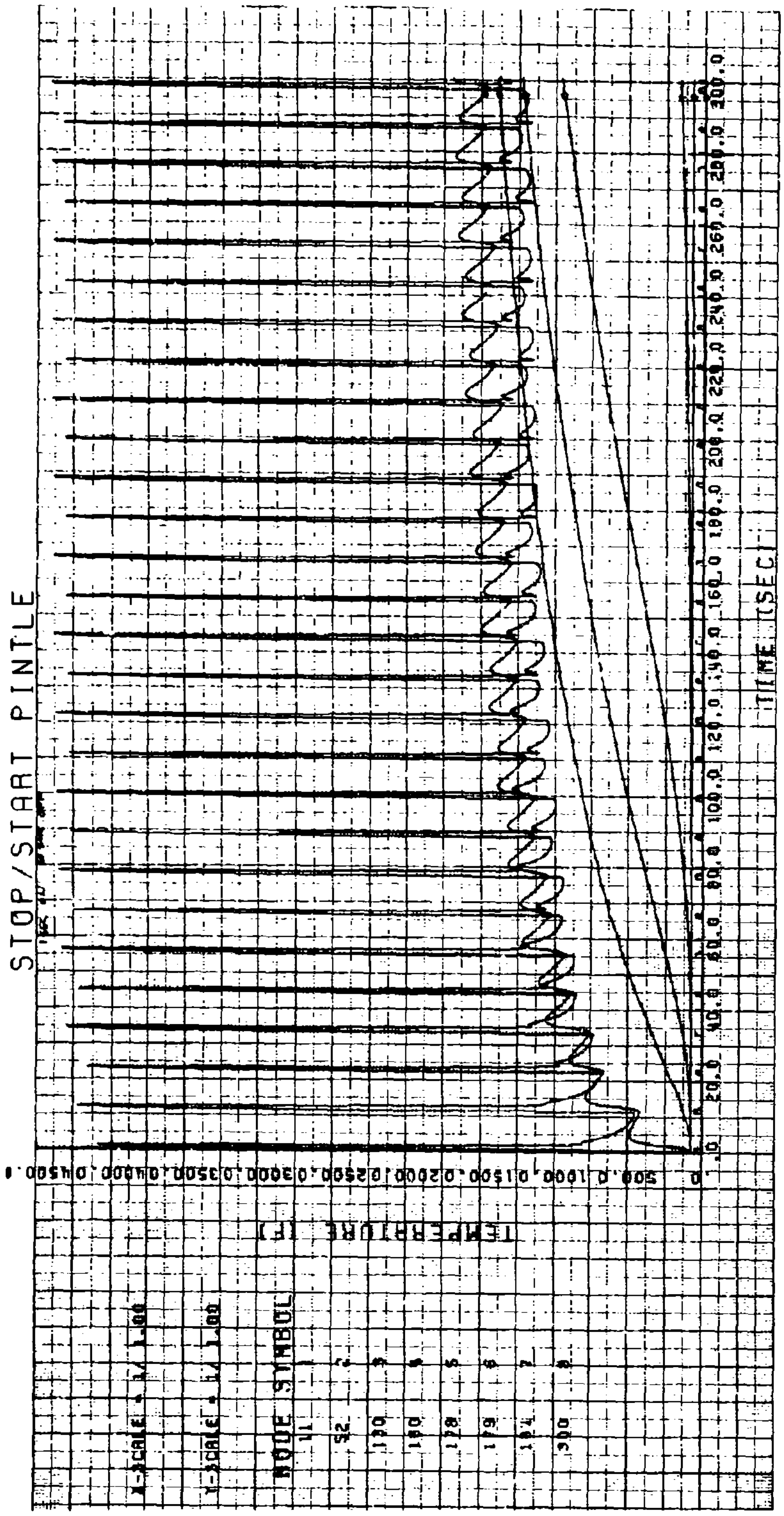

STOP/START PINTLE
TIME (SEC)
TEMPERATURE (F)
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL

Figure V-4

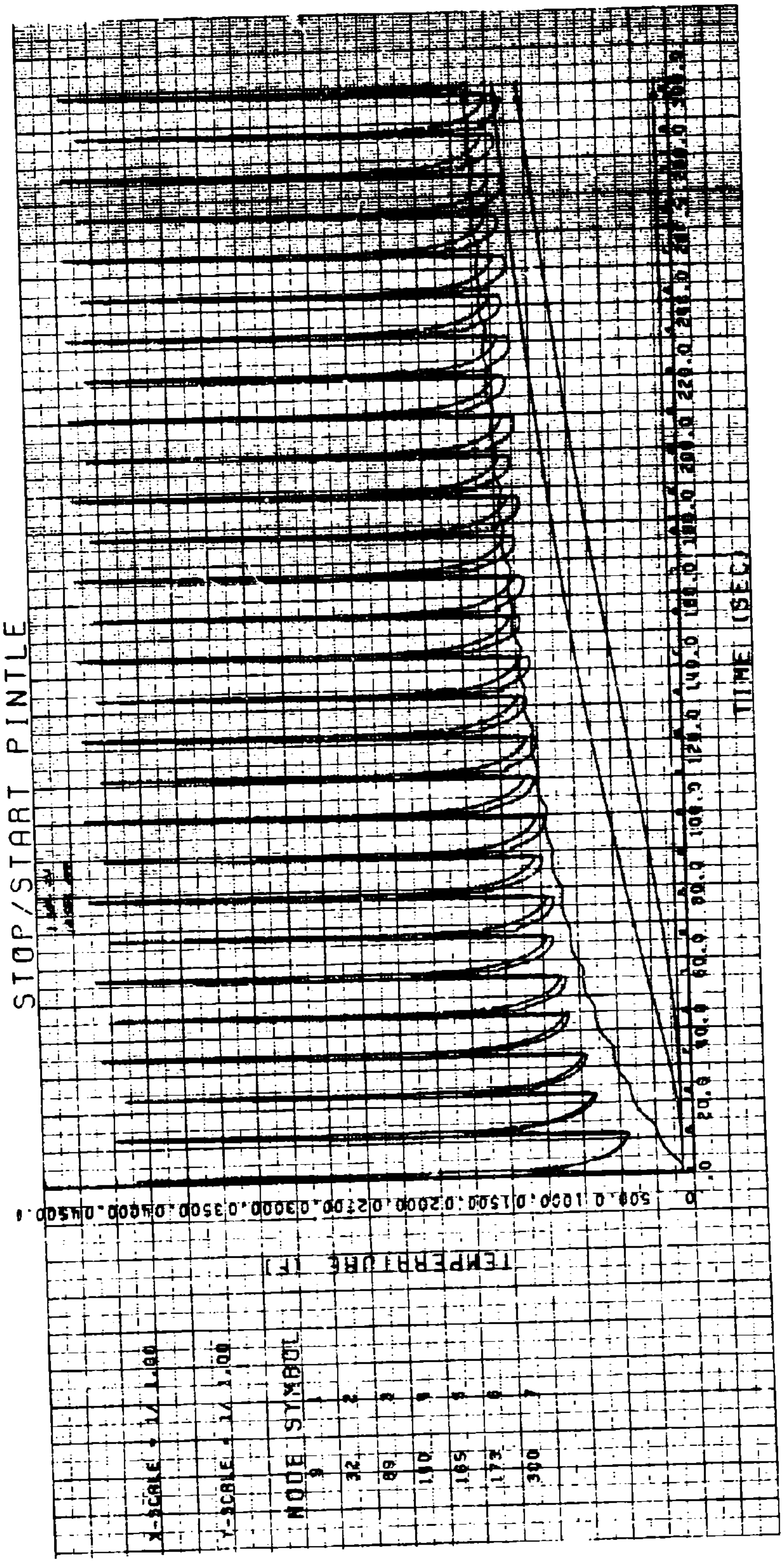

STOP/START PINTLE
TIME (SEC)
TEMPERATURE (F)
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL

Figure V-5

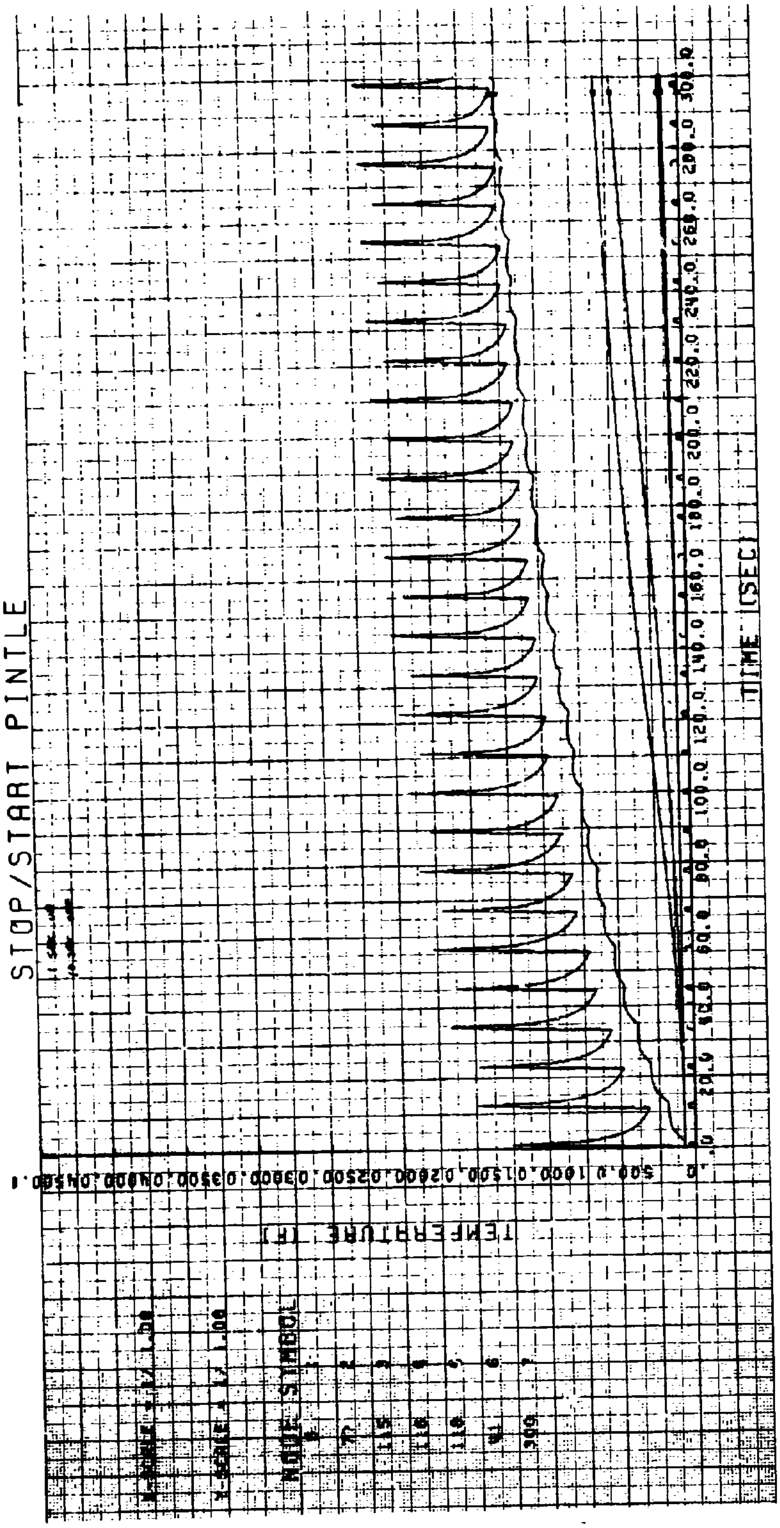


Figure V-6

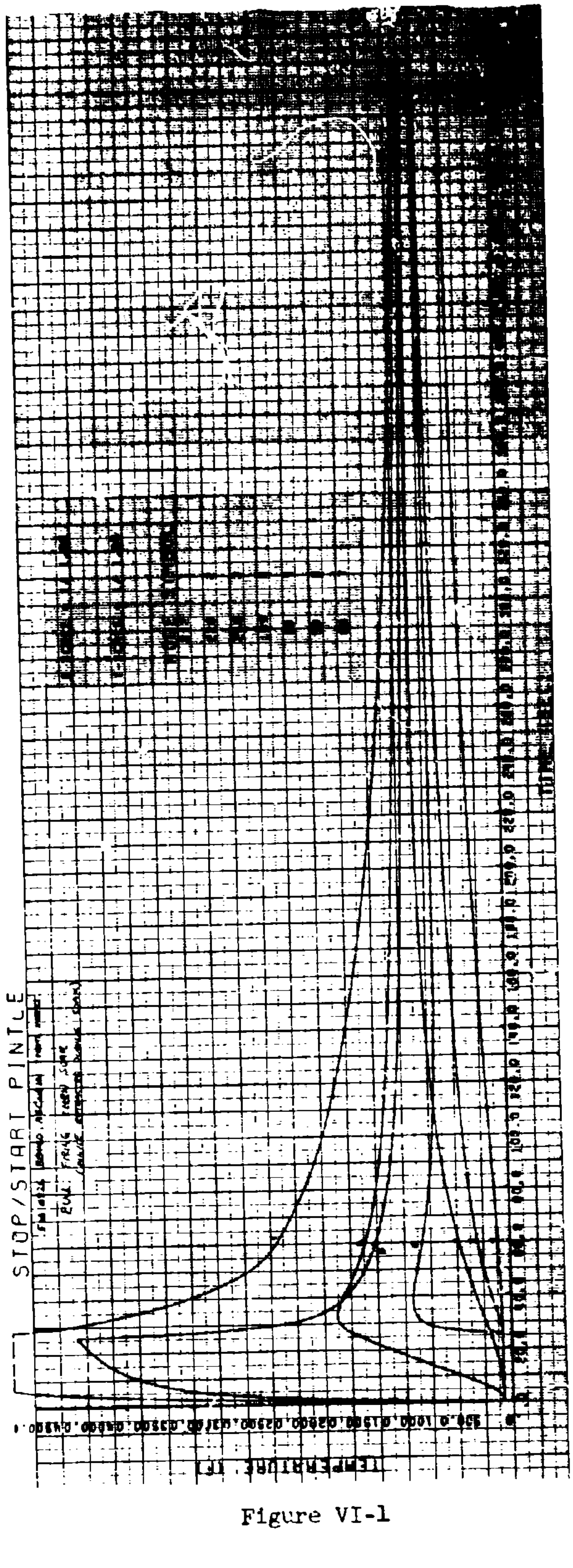


Figure VI-1

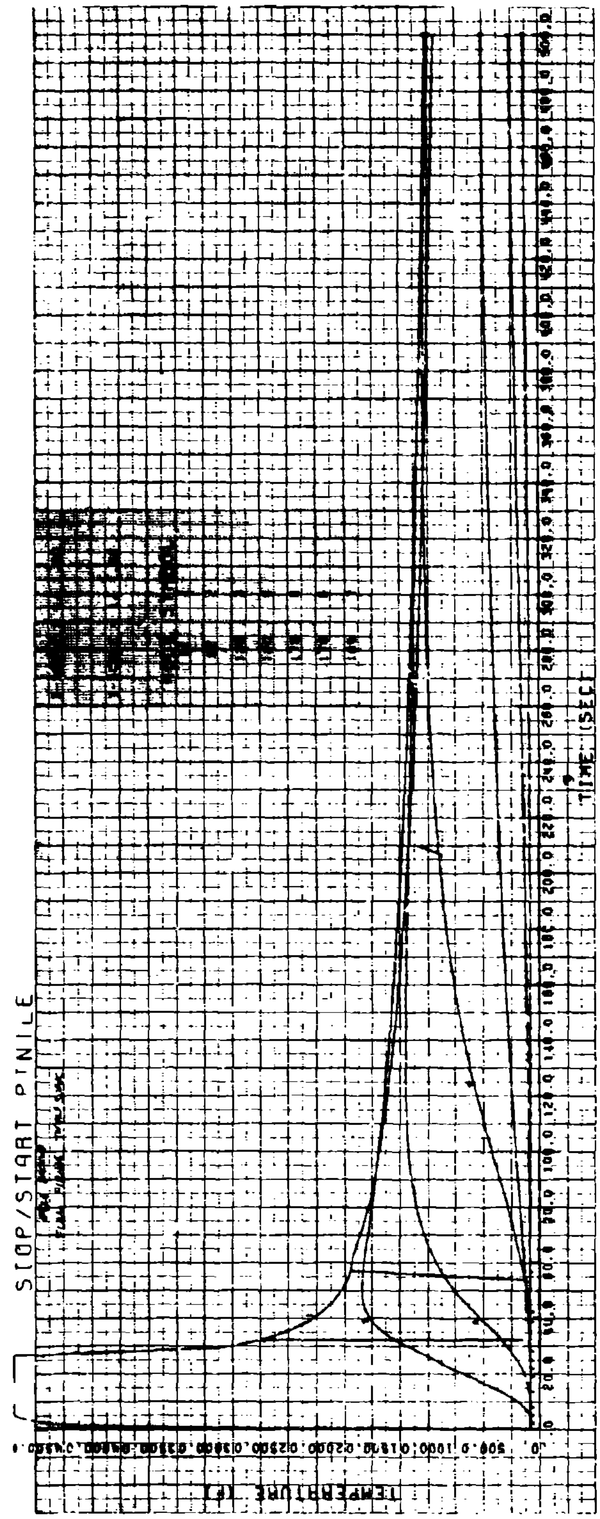


Figure VI-2

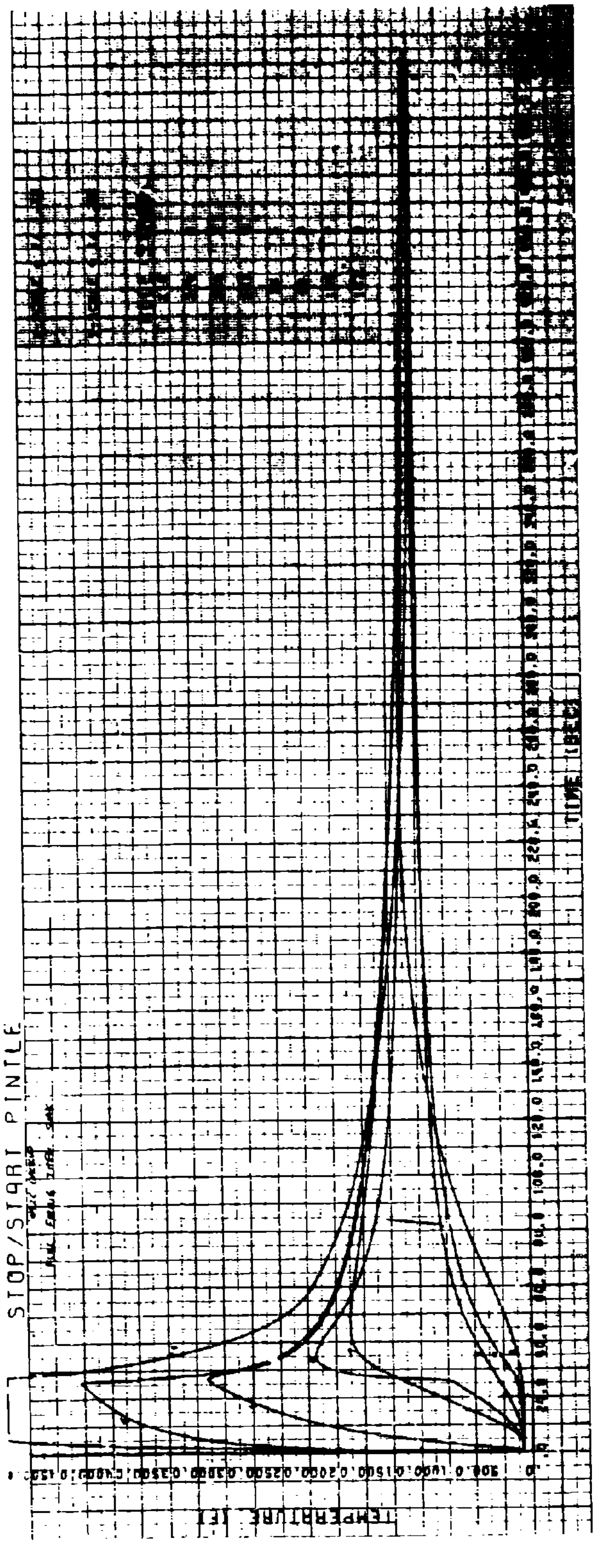


Figure VI-3

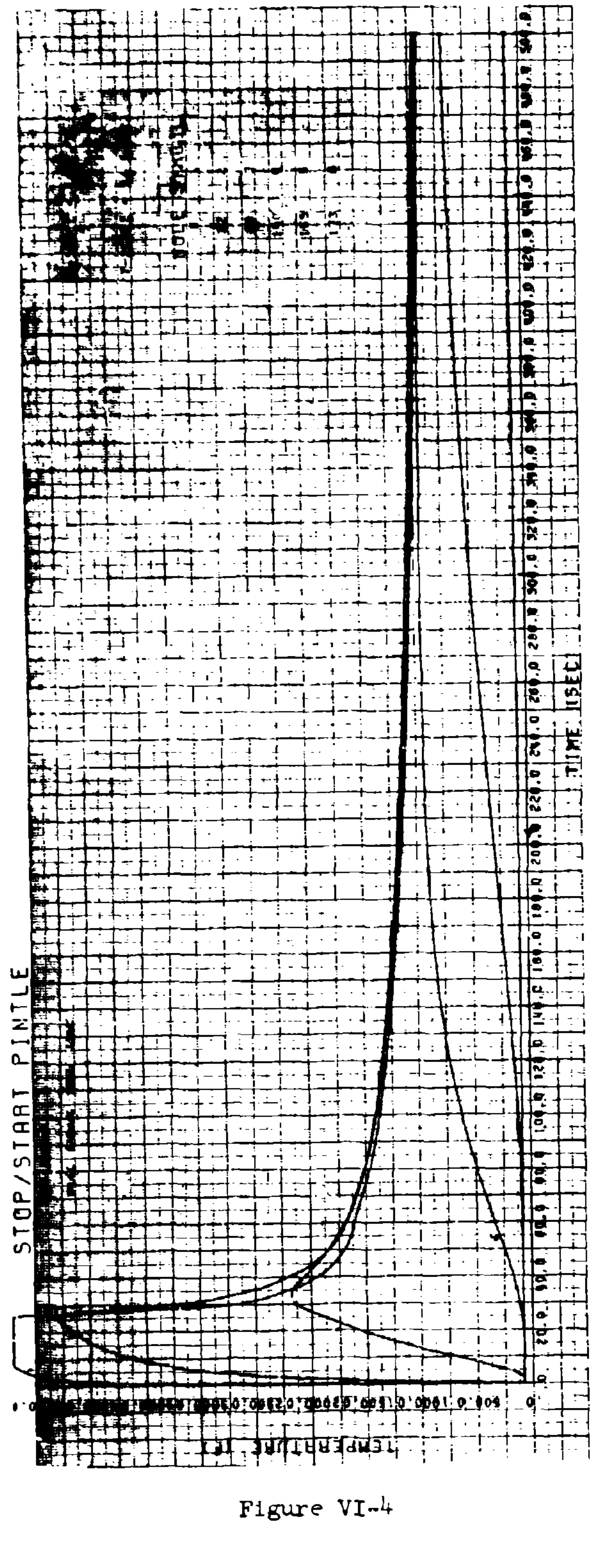


Figure VI-4

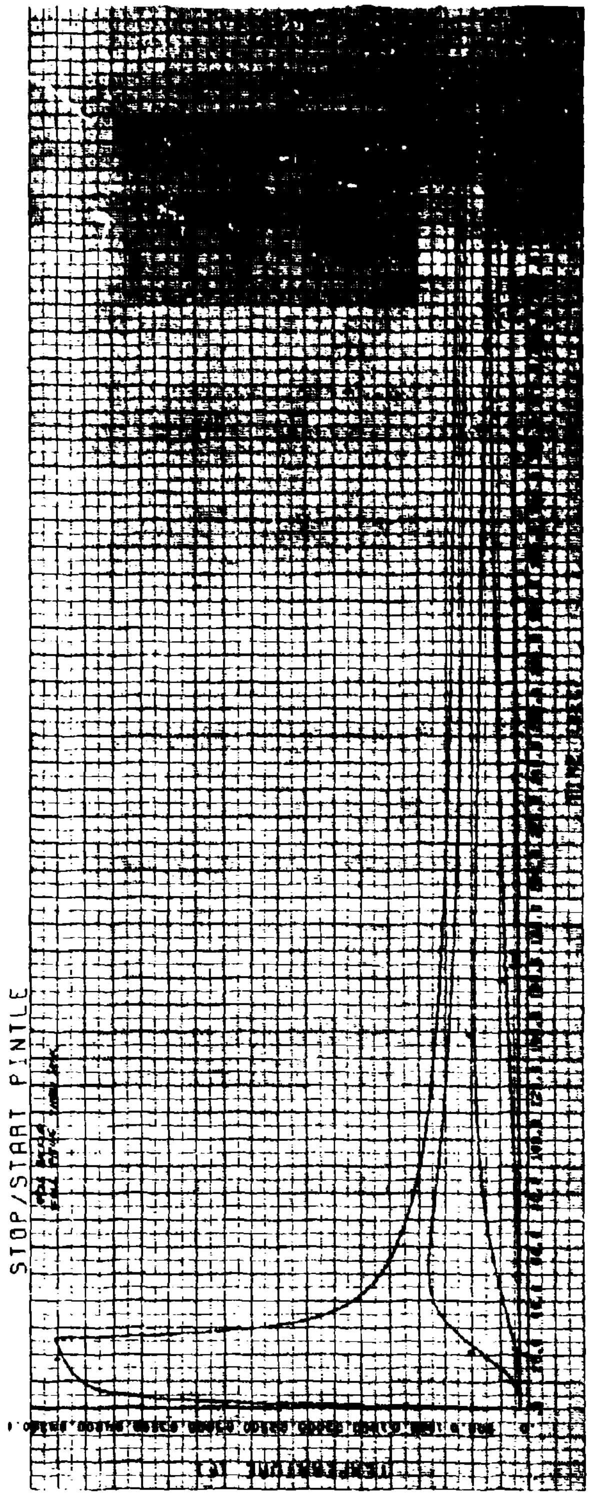


Figure VI-5

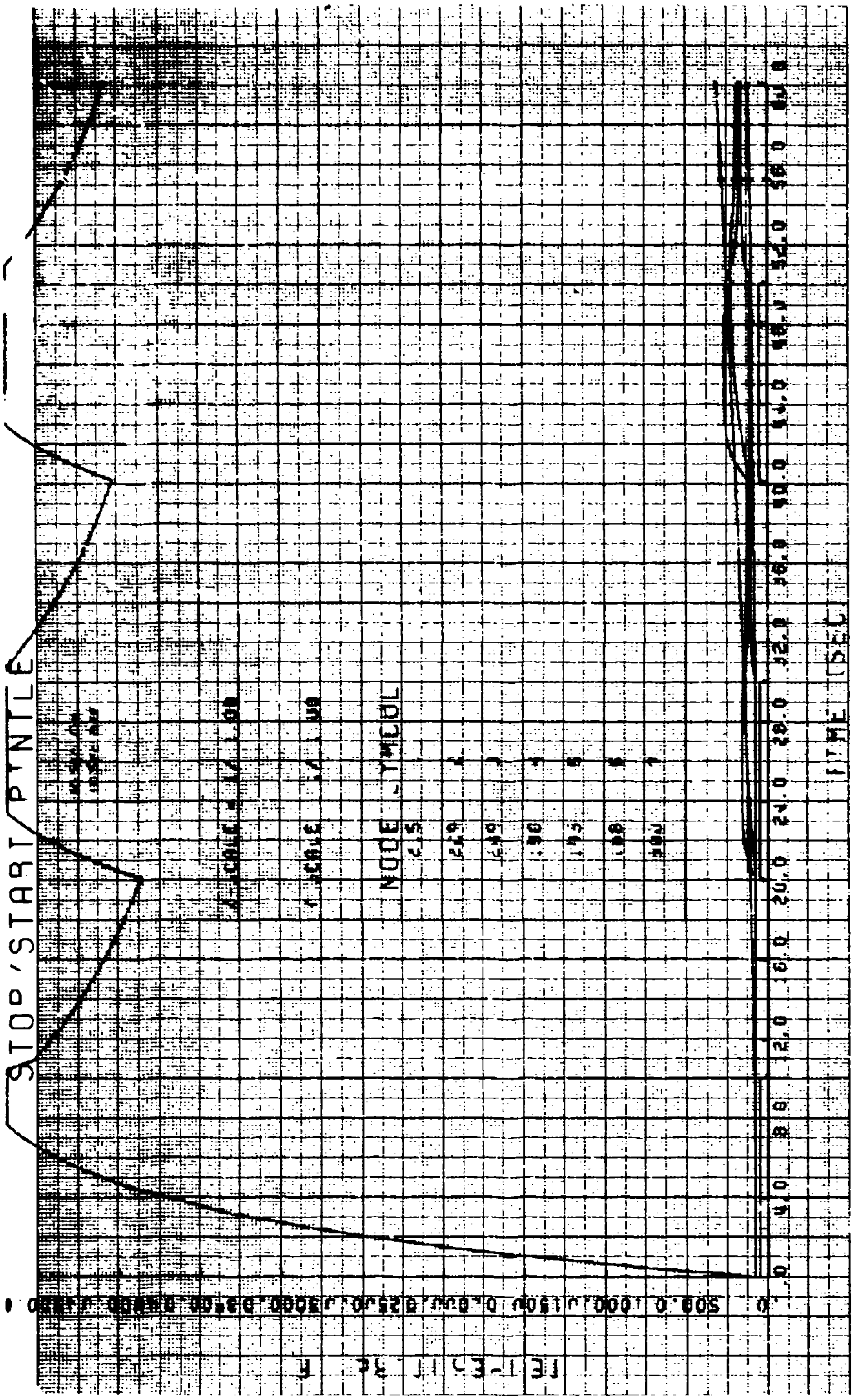


Figure VII-1

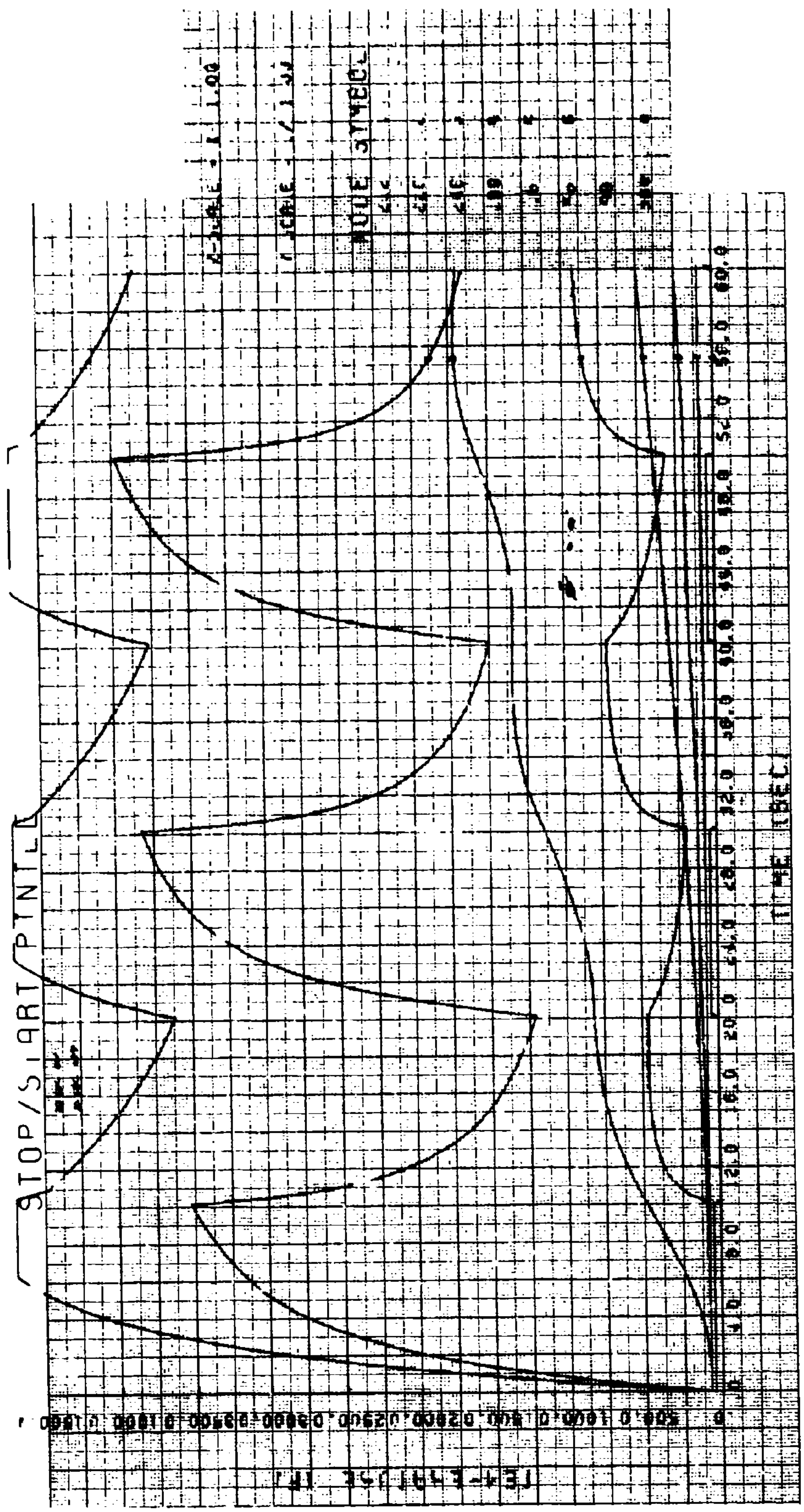


Figure VII-2

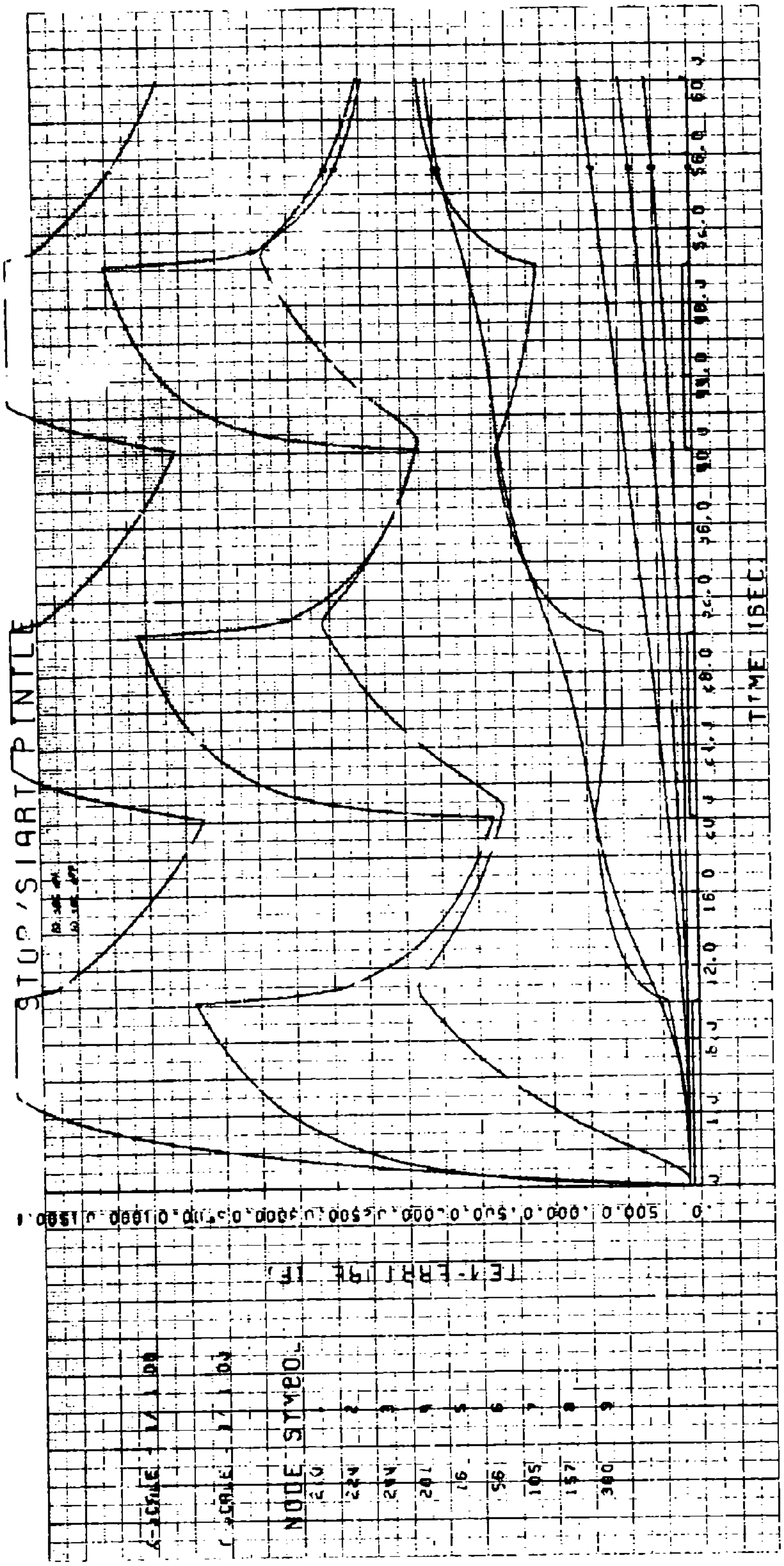


Figure VII-3

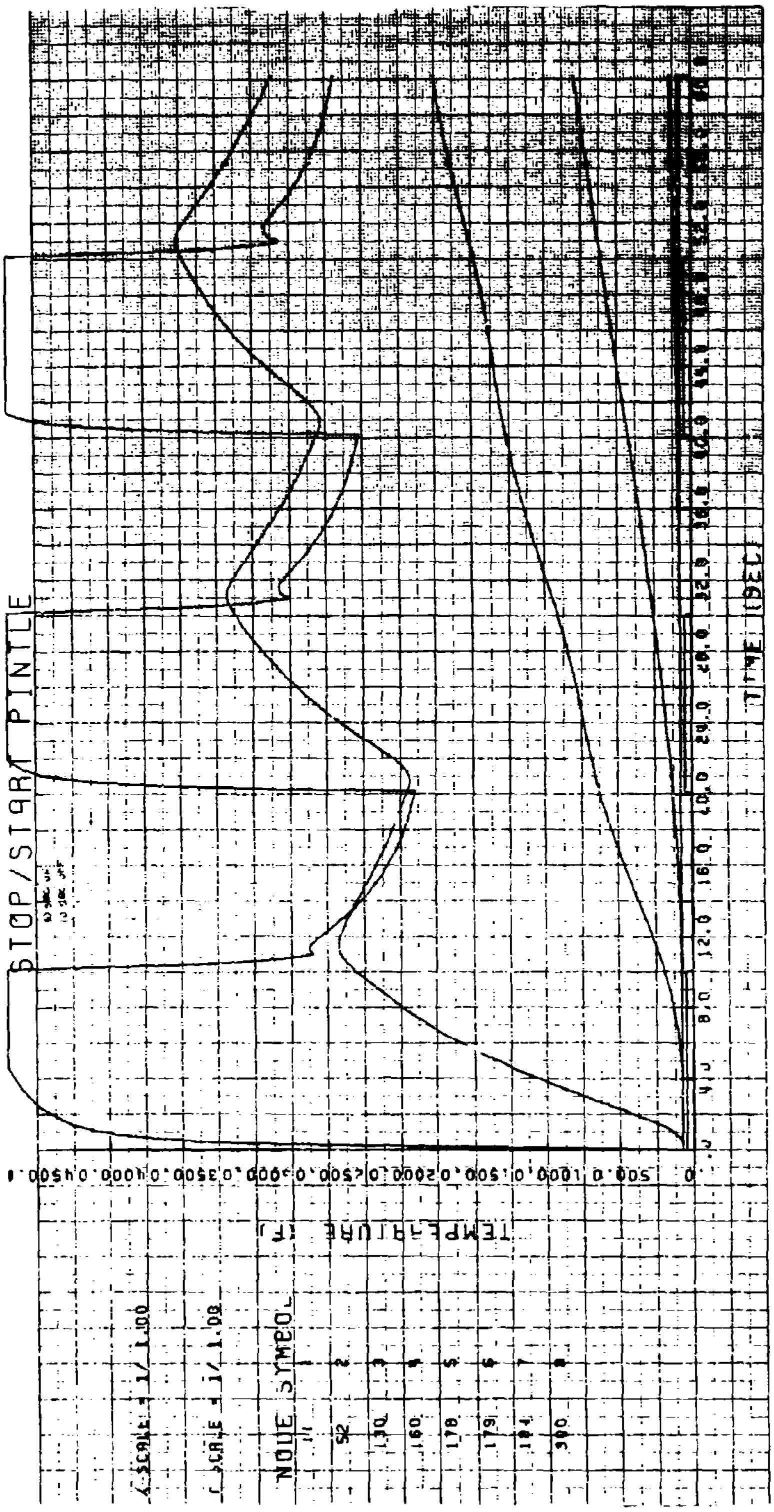


Figure VII-4

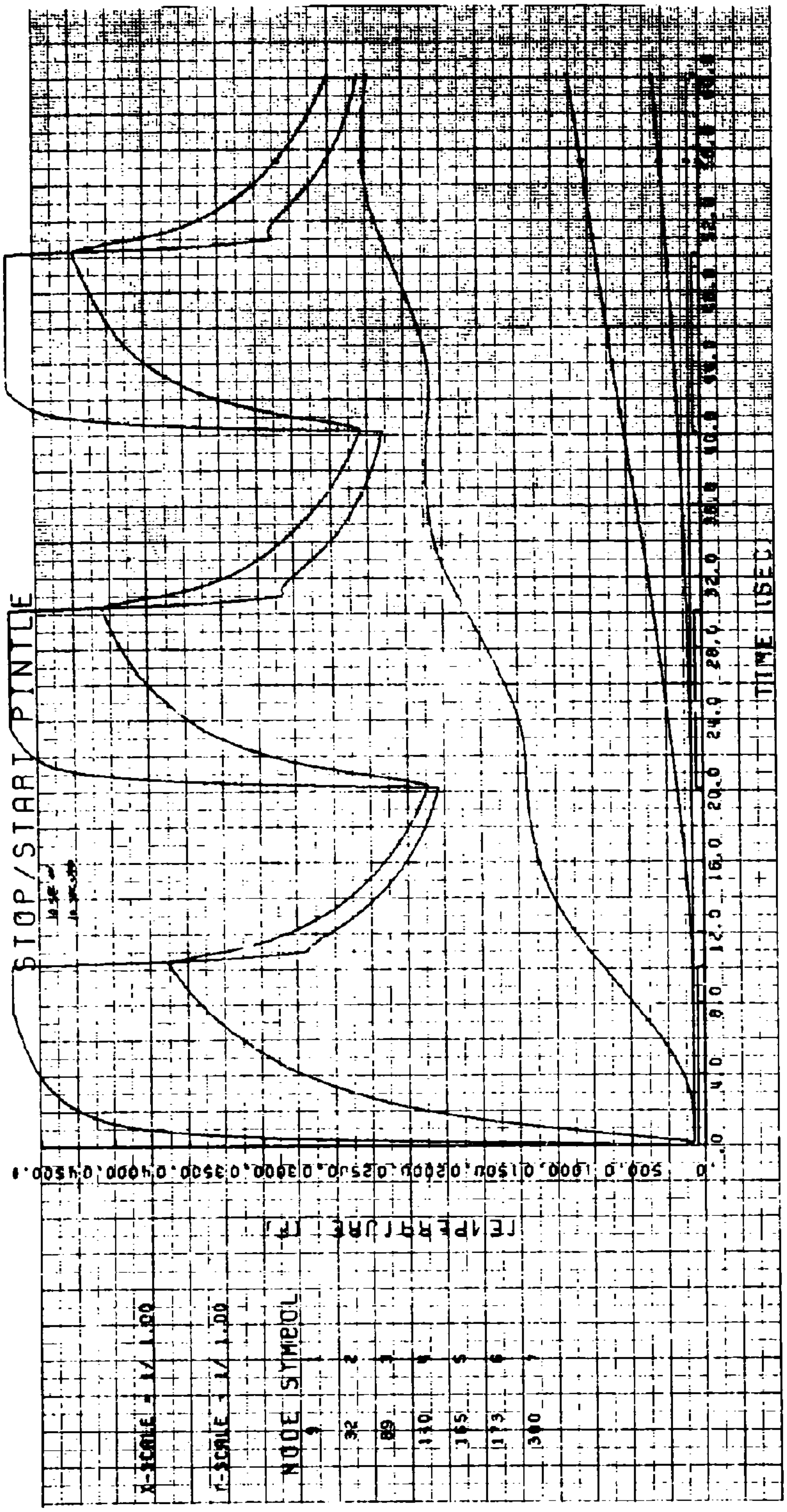

STOP/START PINTLE
TIME (SEC)
TEMPERATURE (F)
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL
9
32
89
110
165
173
300

Figure VII-5

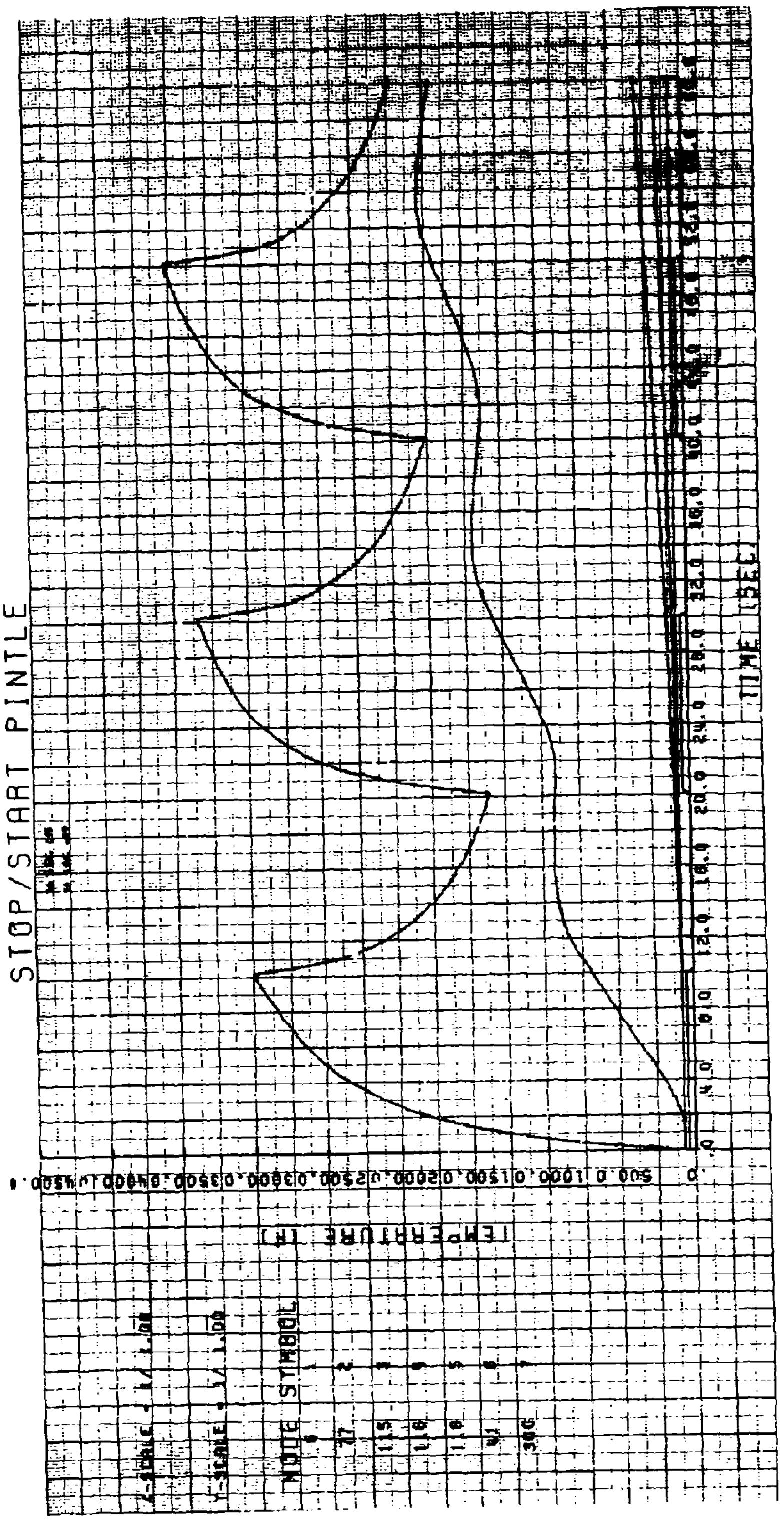


Figure VII-6

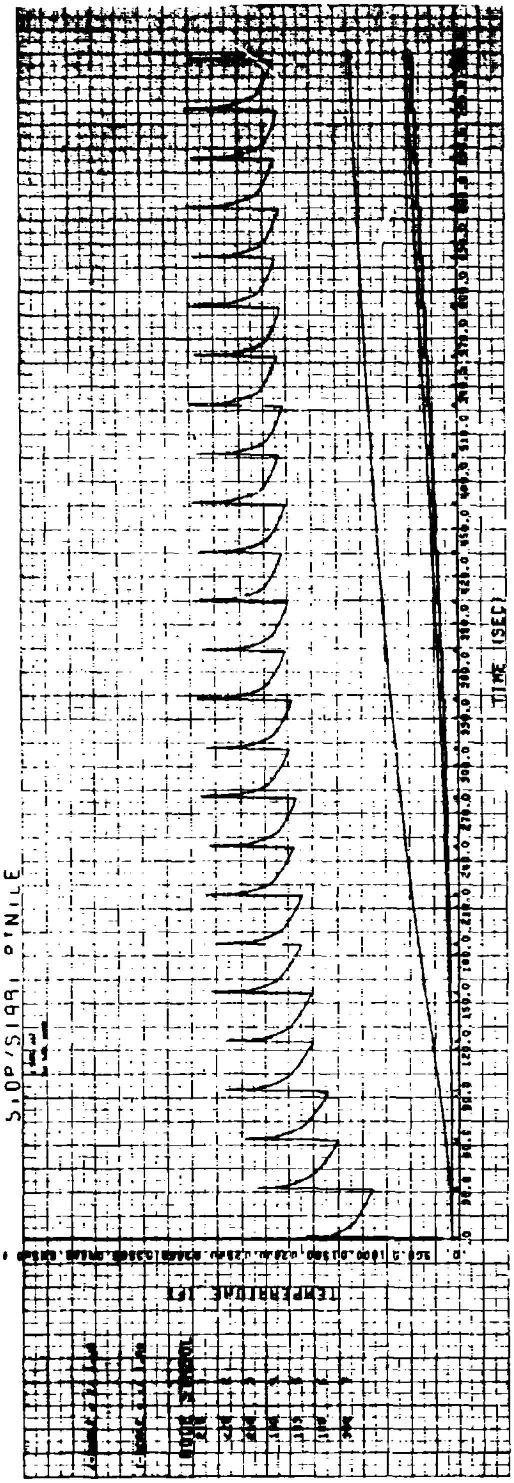


Figure VIII-1

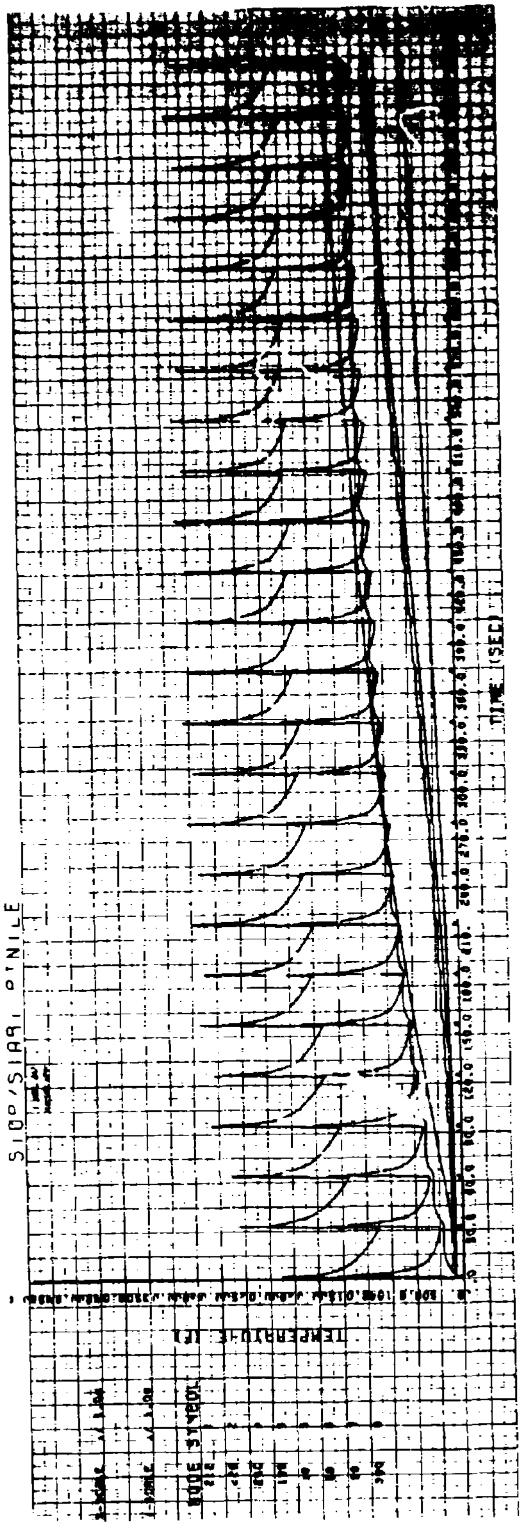


Figure VIII-2

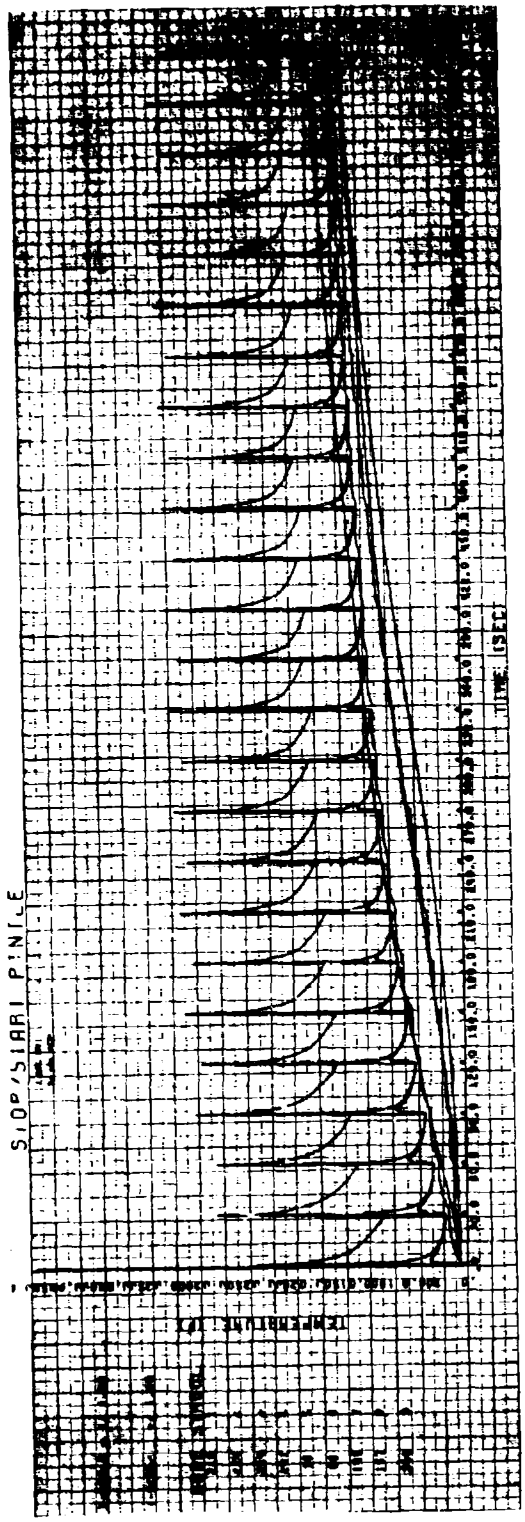


Figure VIII-3

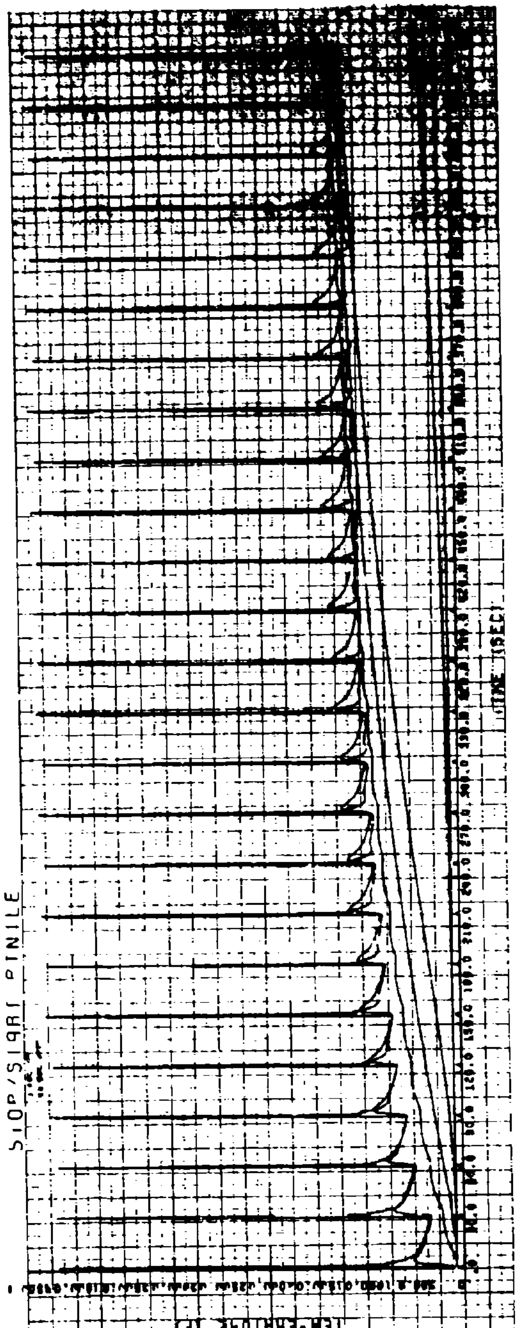


Figure VIII-4

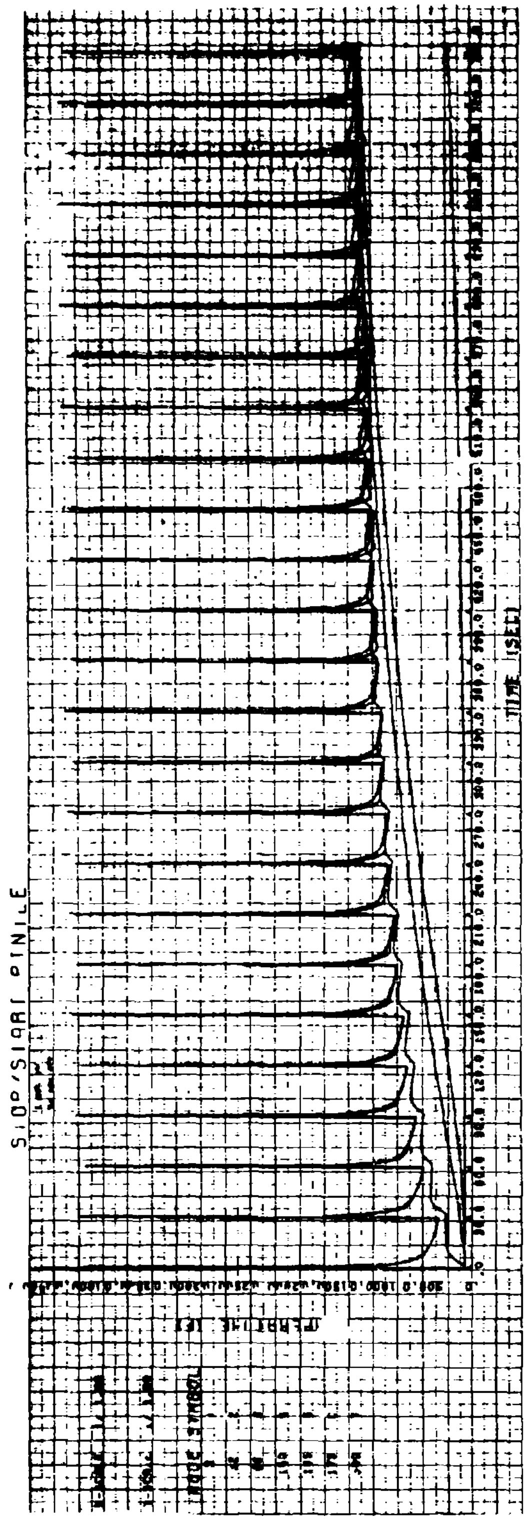


Figure VIII-5

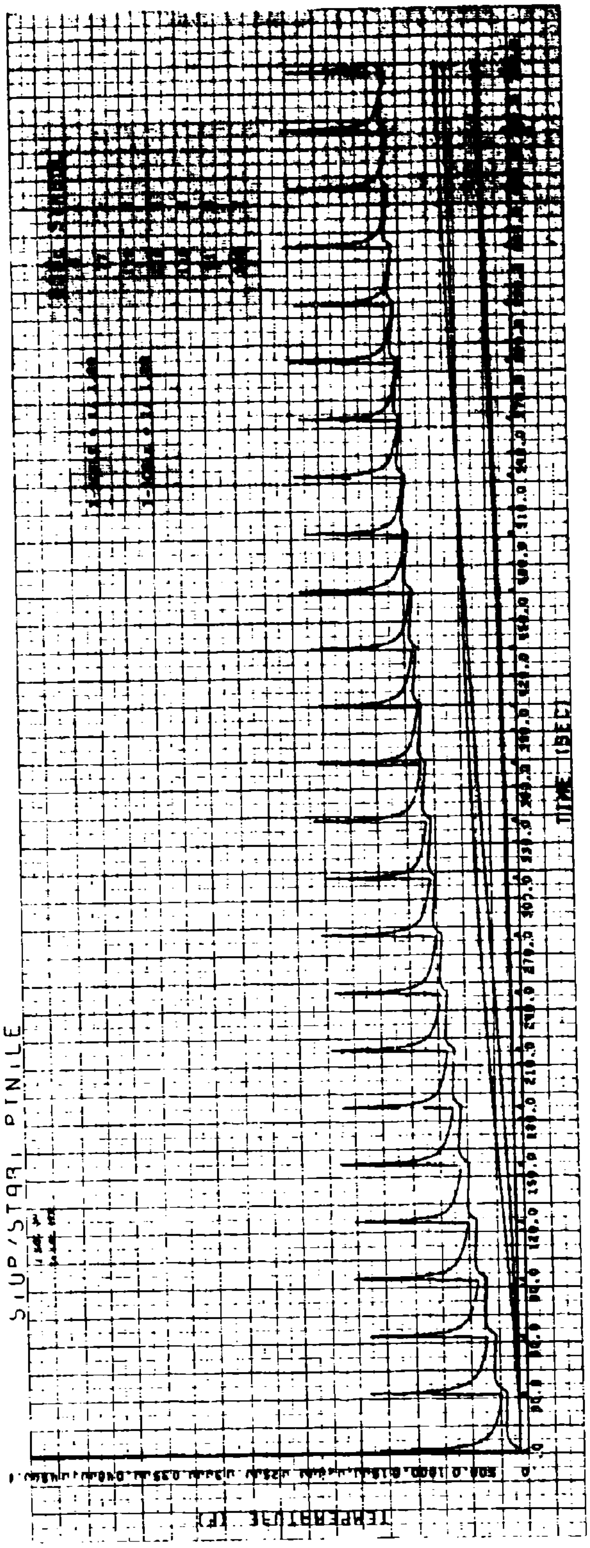


Figure VIII-6

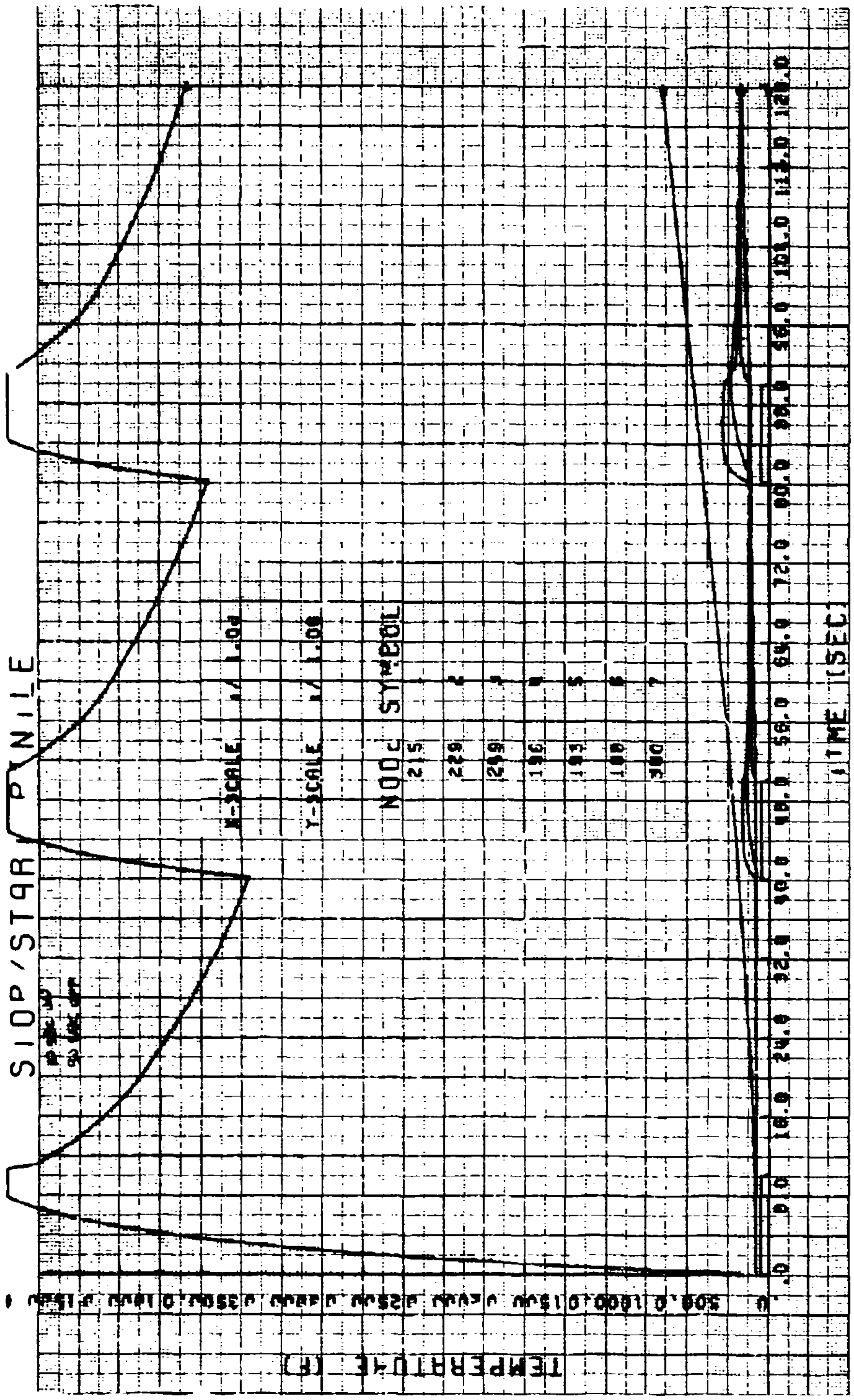


Figure IX-1

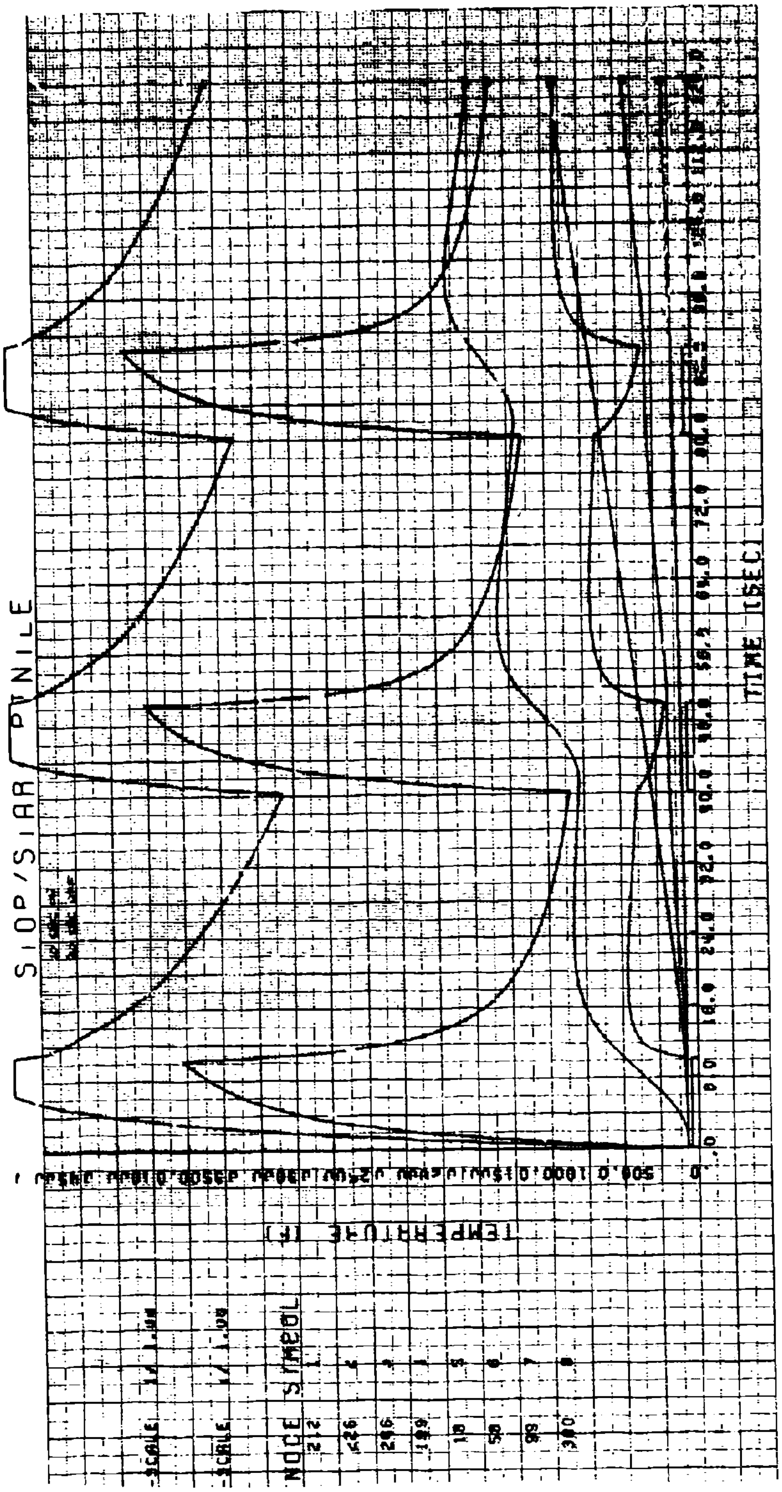


Figure IX-2

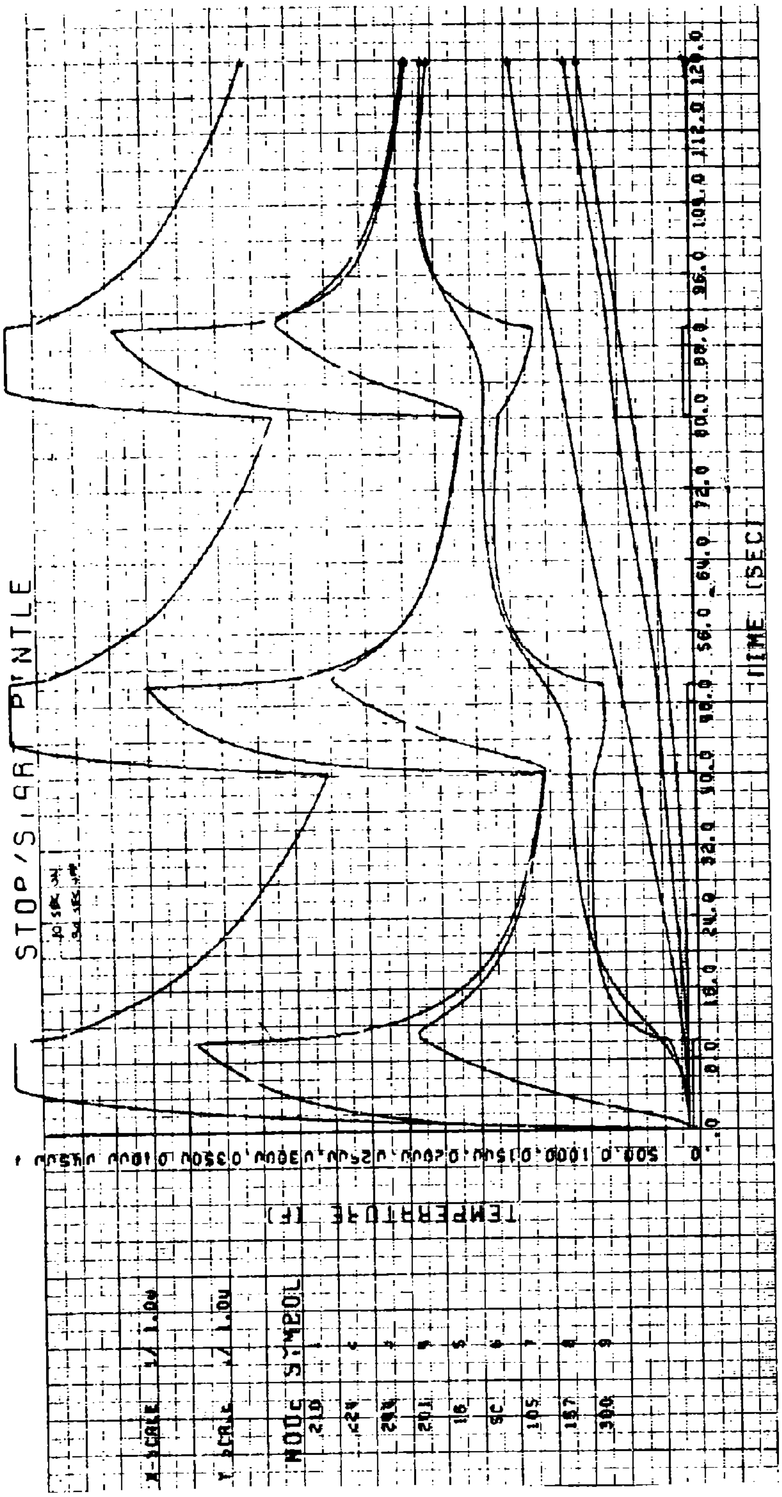


Figure IX-3

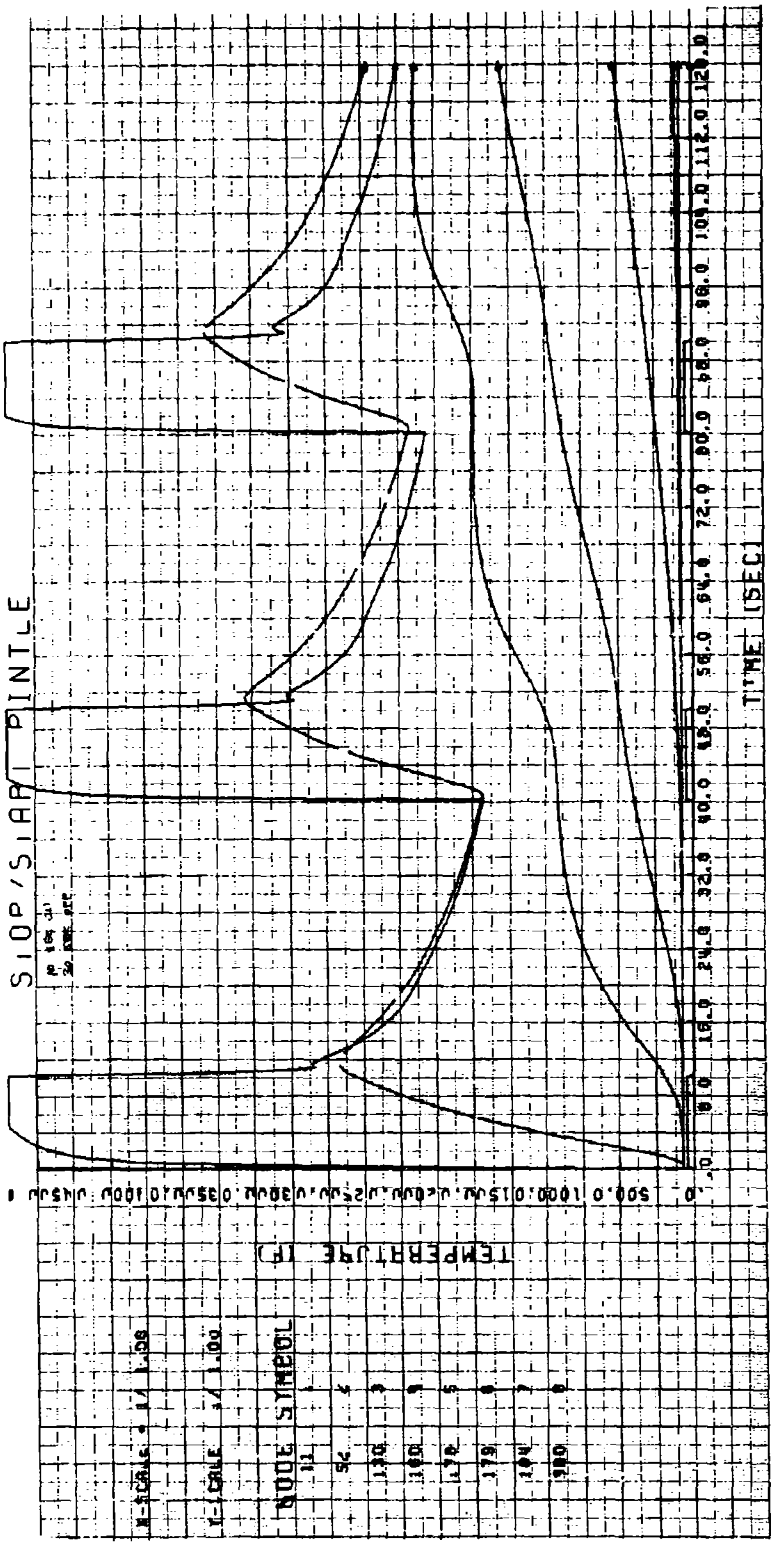


Figure IX-4

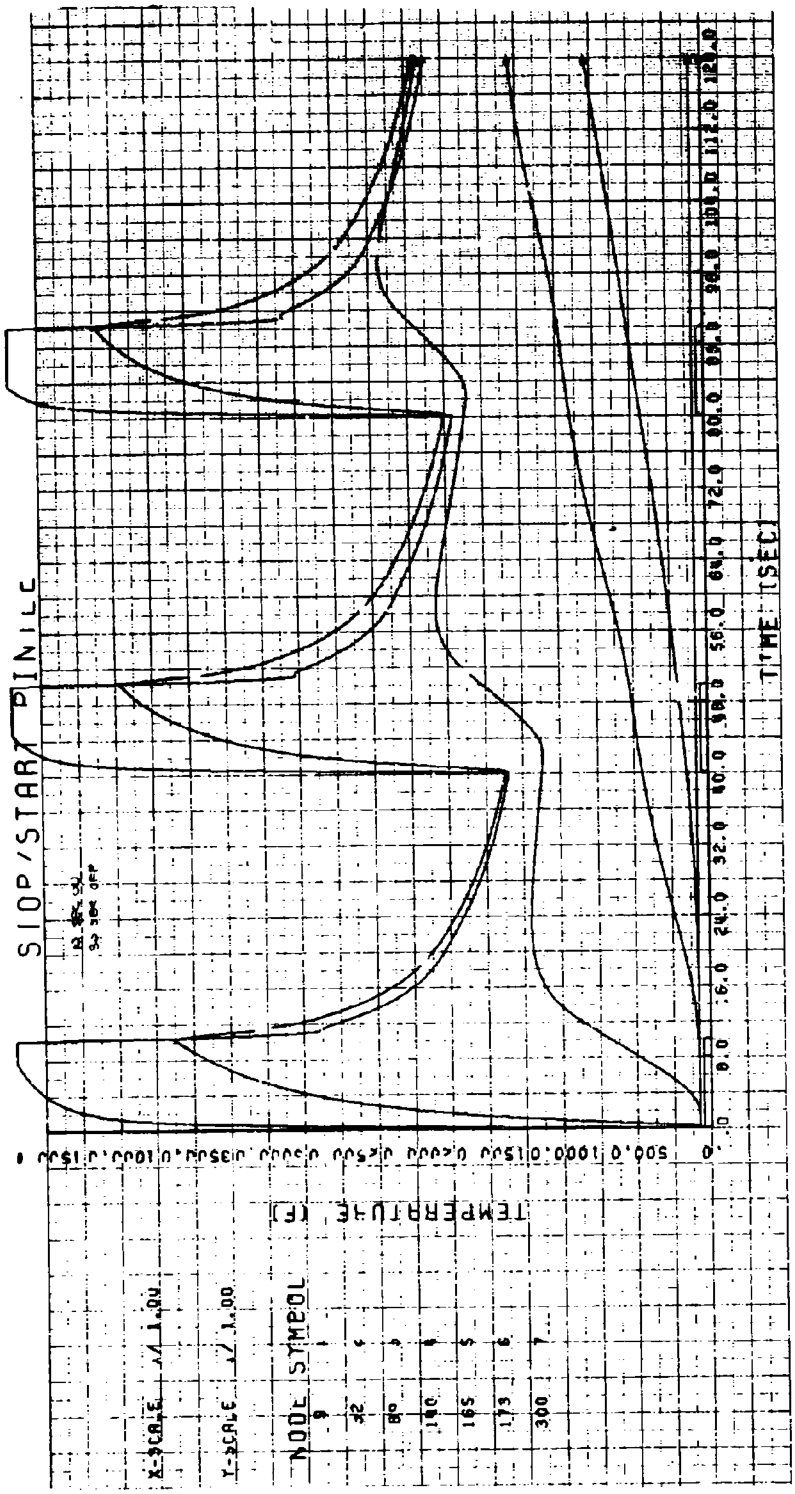


Figure IX-5

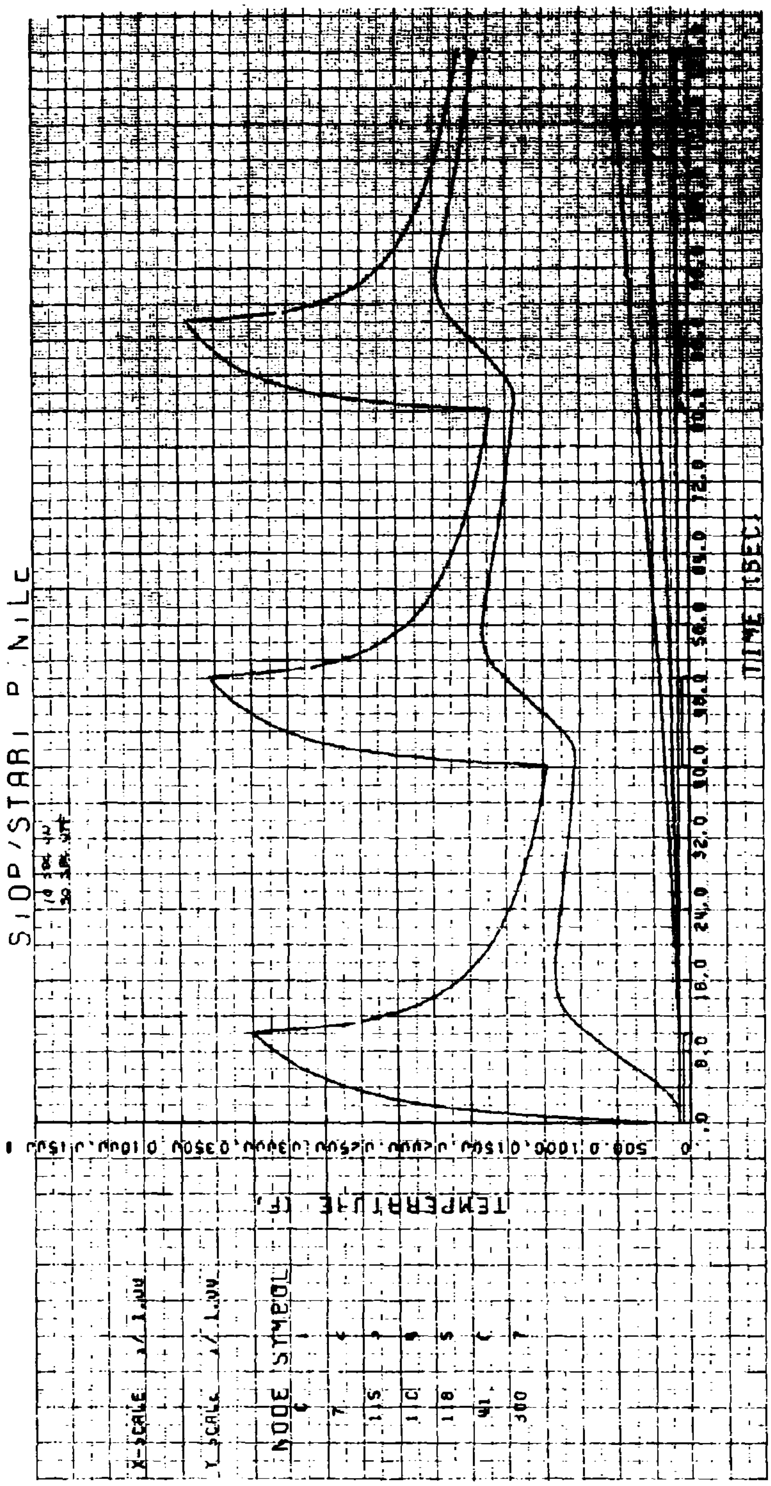


Figure IX-6

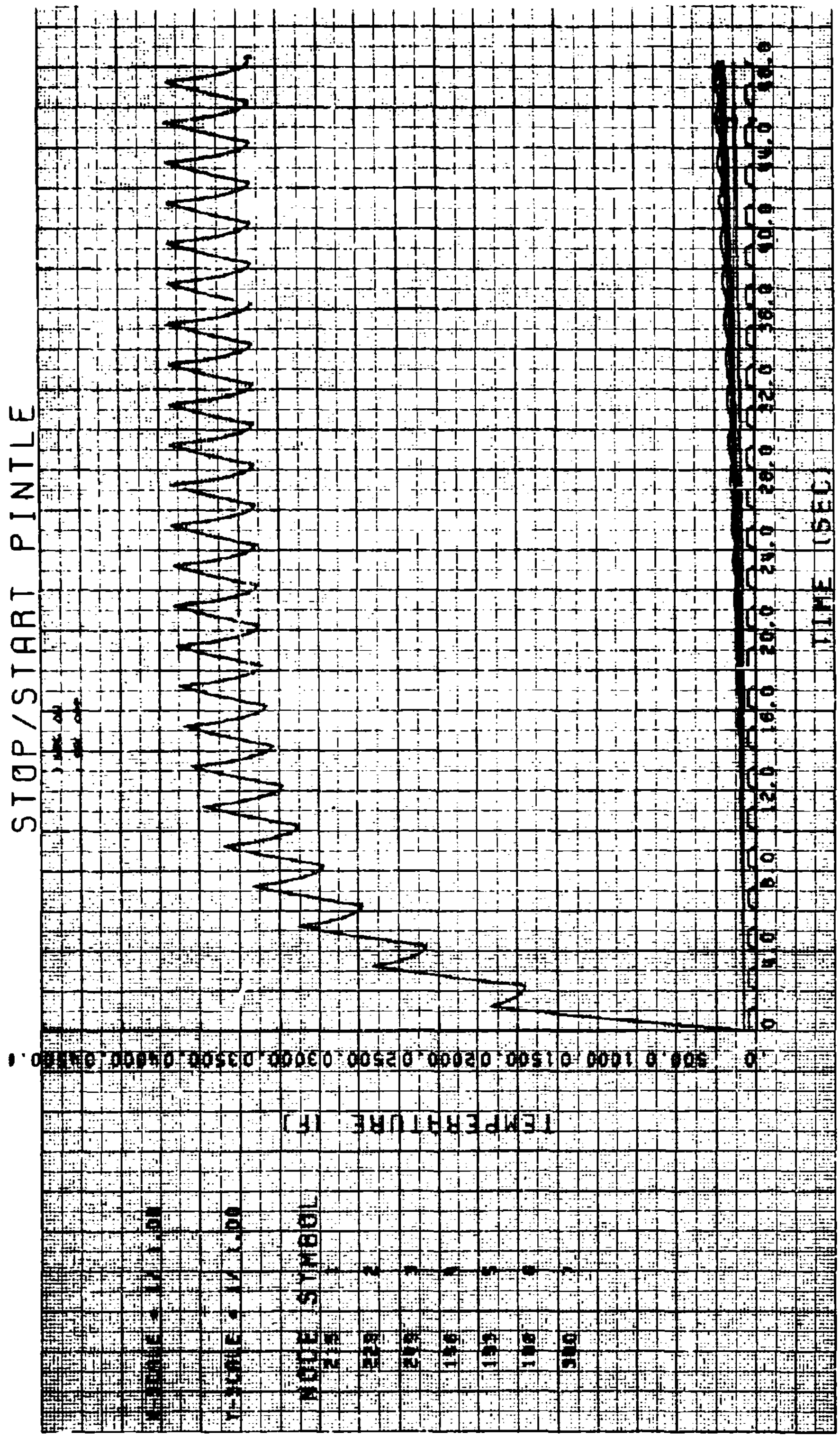


Figure X-1

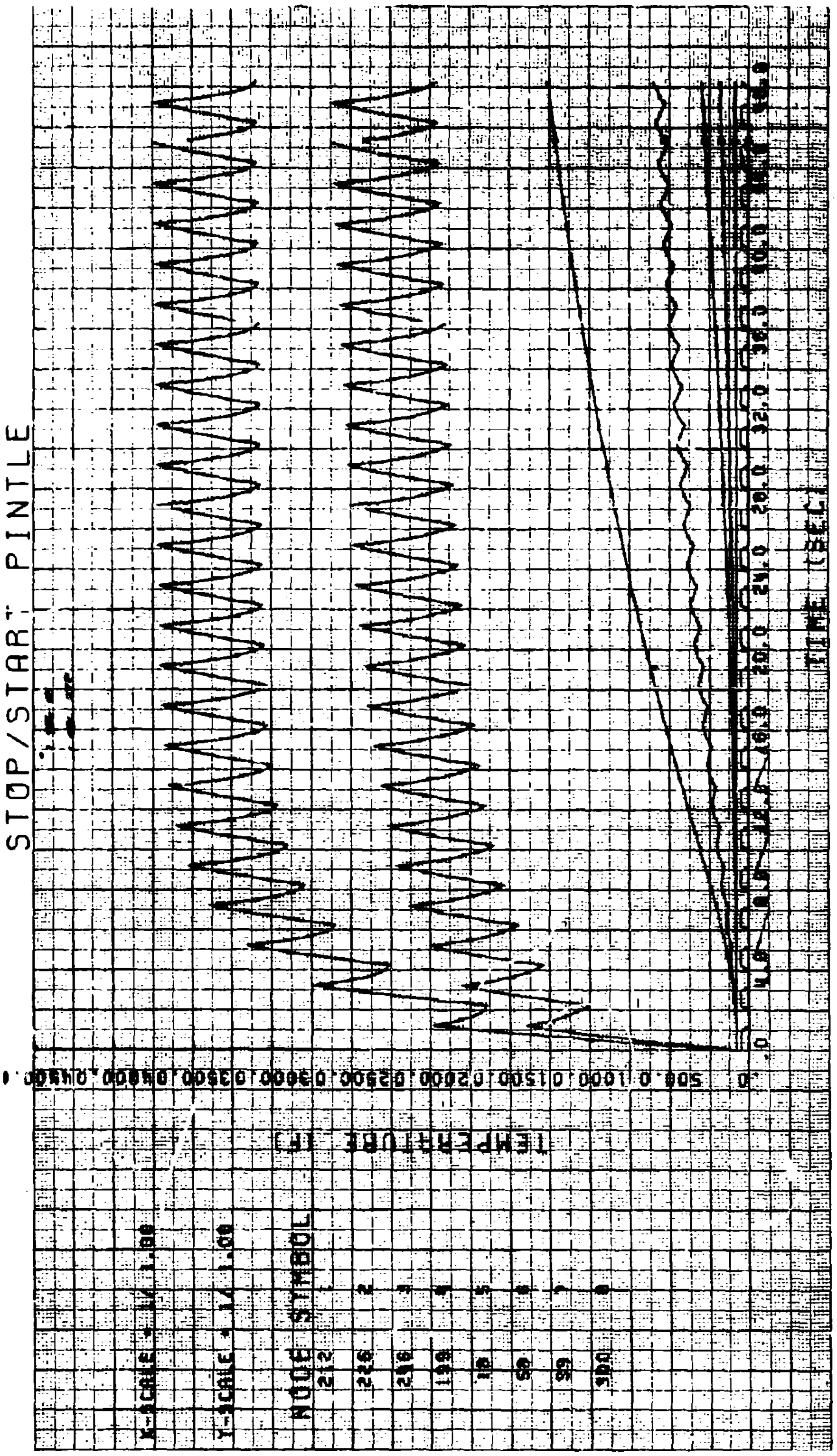


Figure X-2

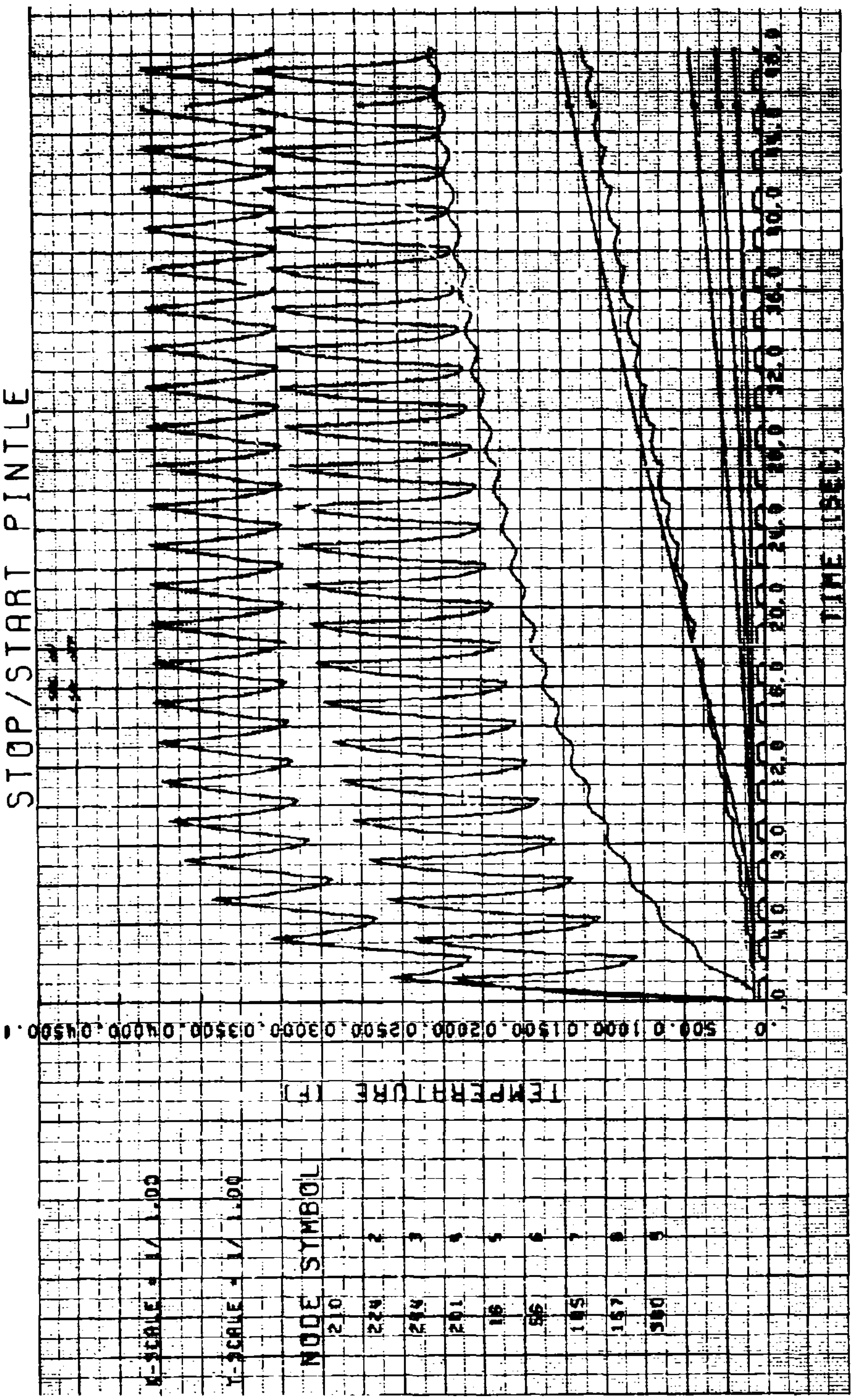


Figure X-3

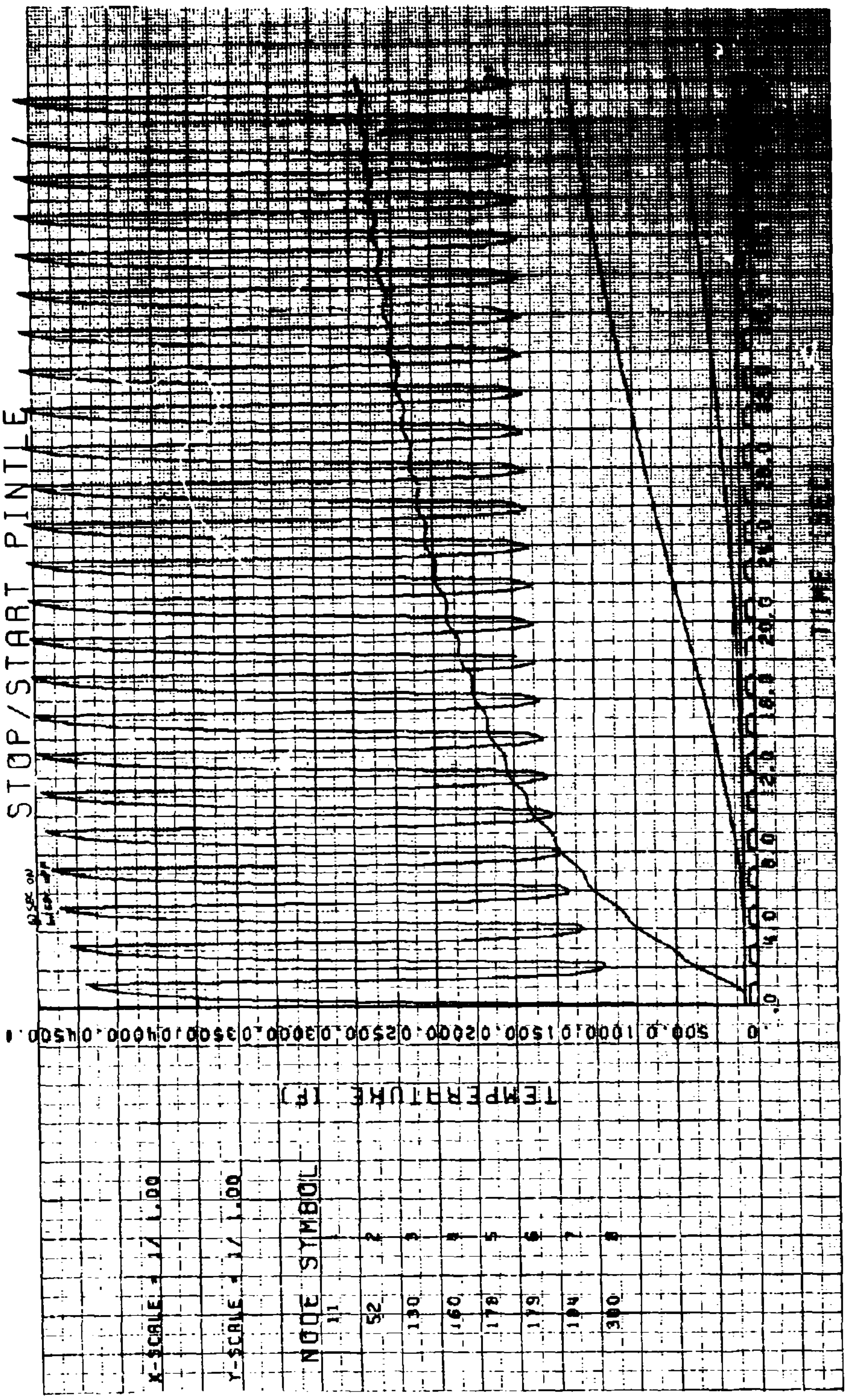

STOP/START PINTLE
TEMPERATURE (F)
0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL
11
52 2
130 3
160 4
178 5
179 6
194 7
300 8

Figure X-4

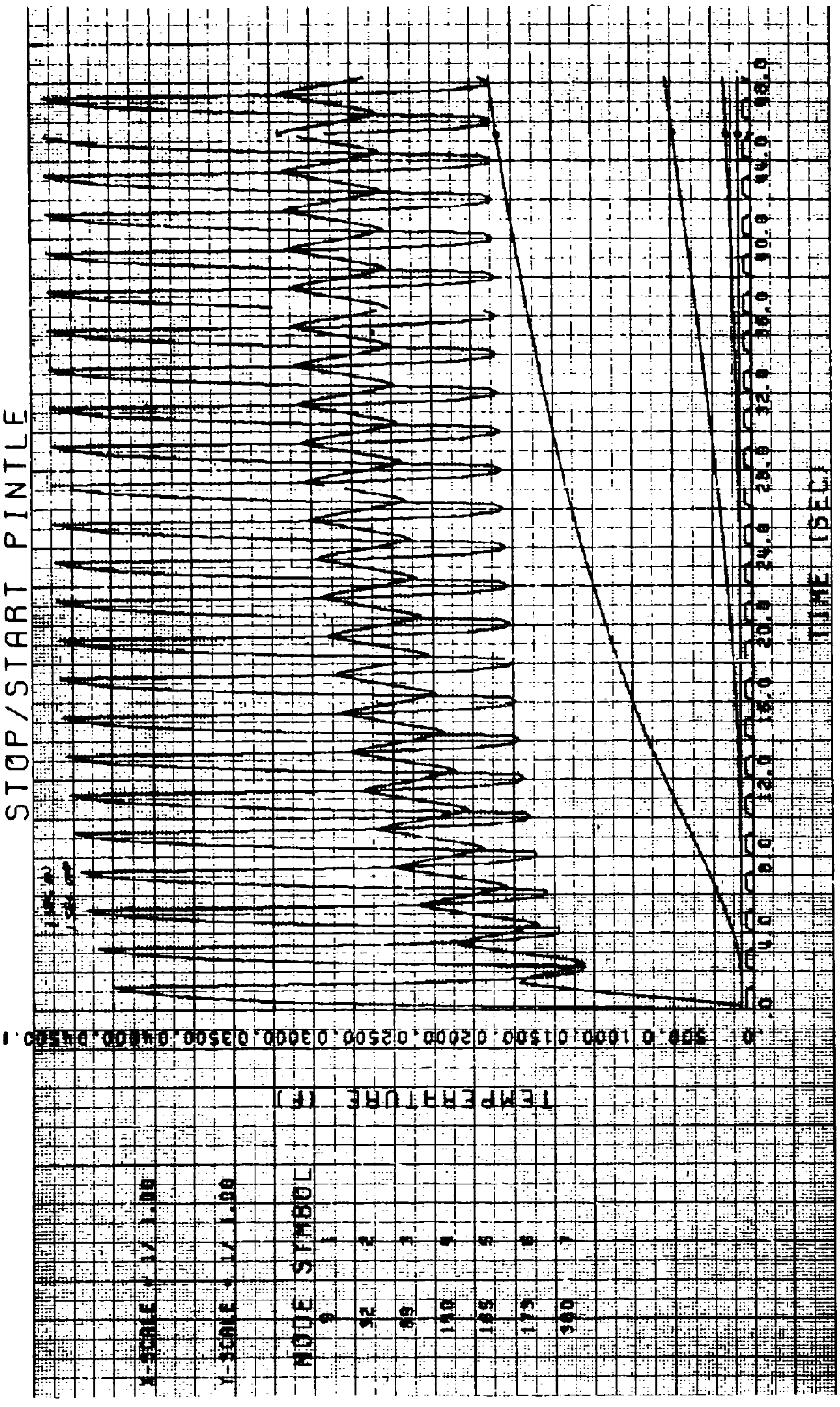


Figure X-5

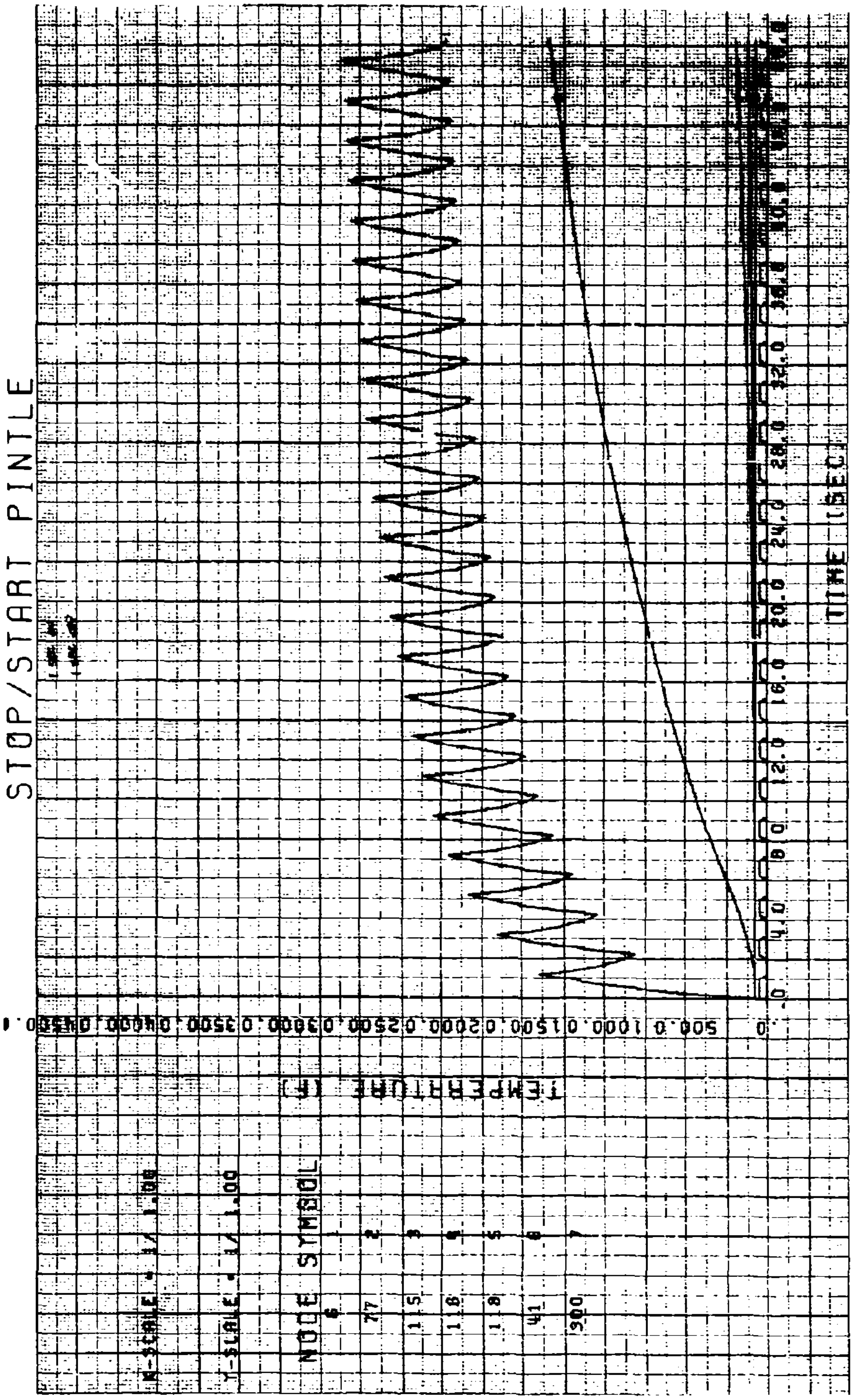

STOP/START PINTLE
TIME (SEC)
TEMPERATURE (F)
X-SCALE = 1/ 1.00
Y-SCALE = 1/ 1.00
NODE SYMBOL

Figure X-6

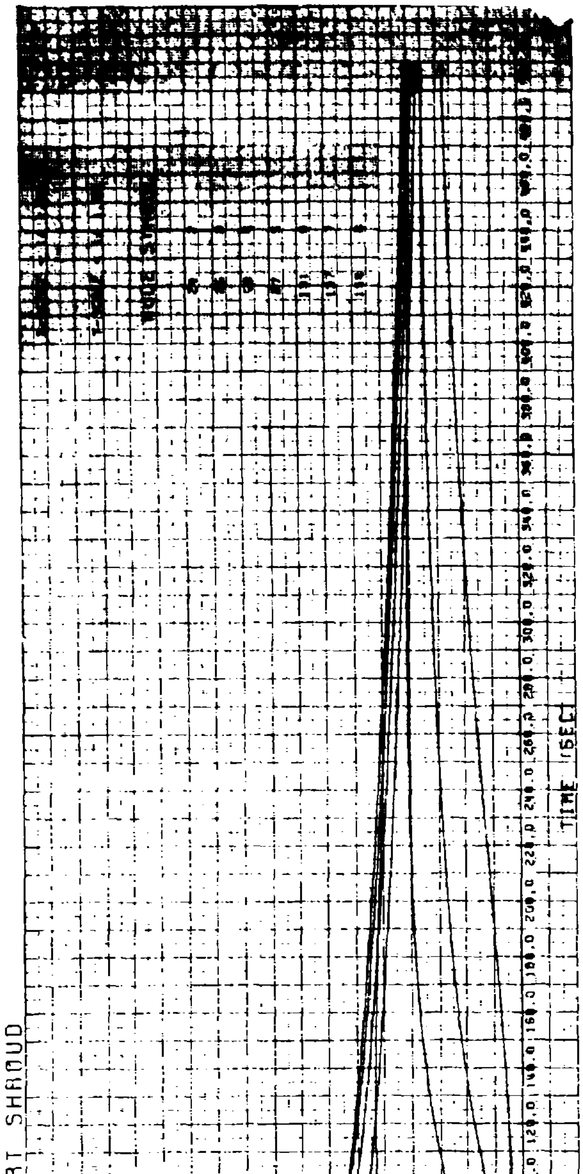


Figure XI-1

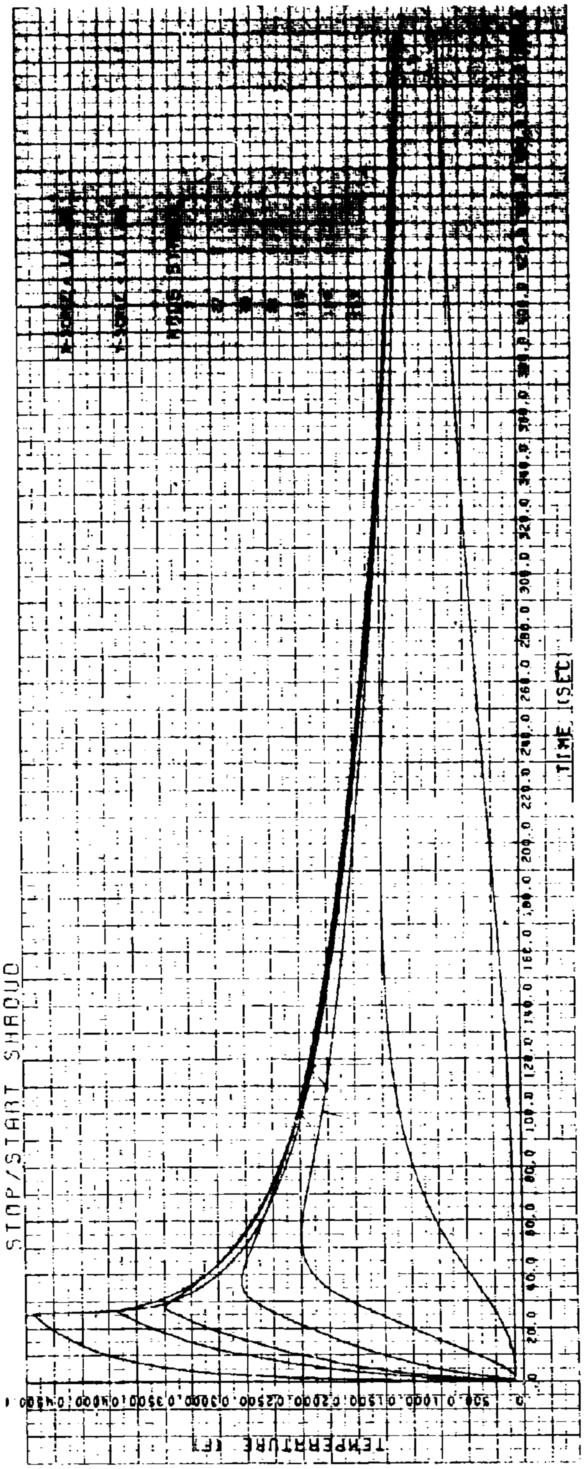


Figure XI-2

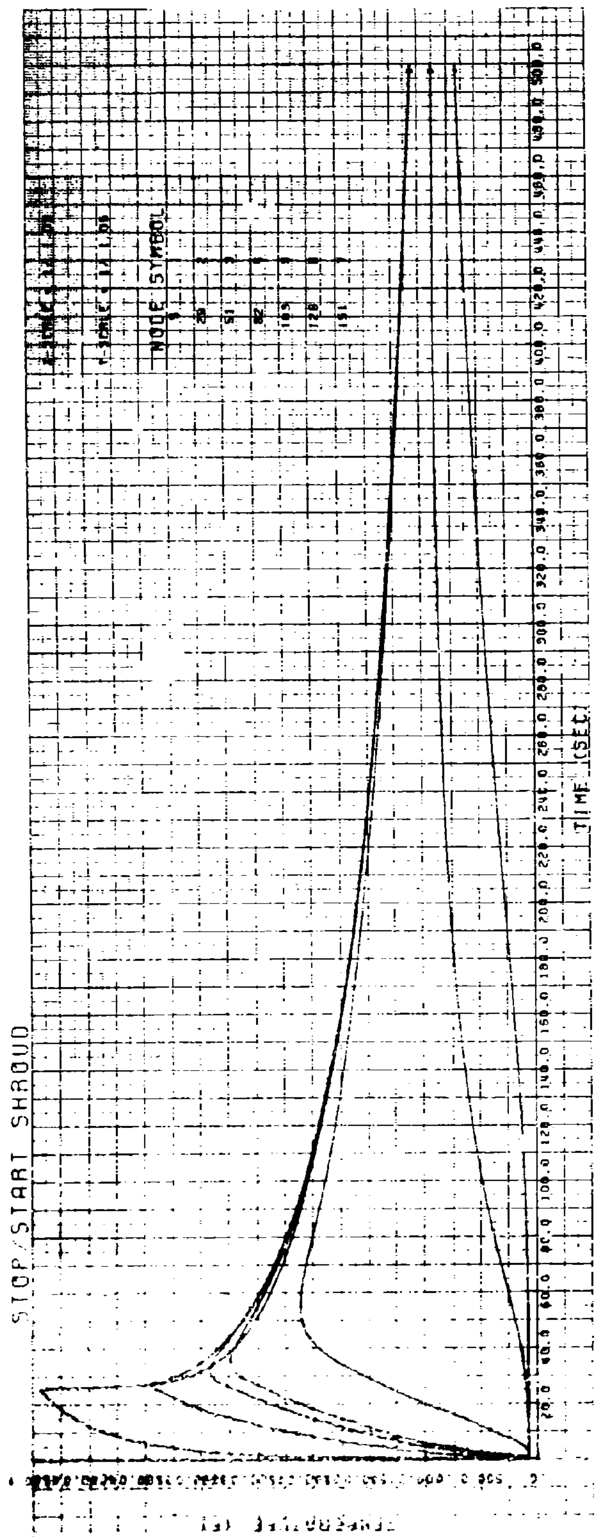


Figure XI-3

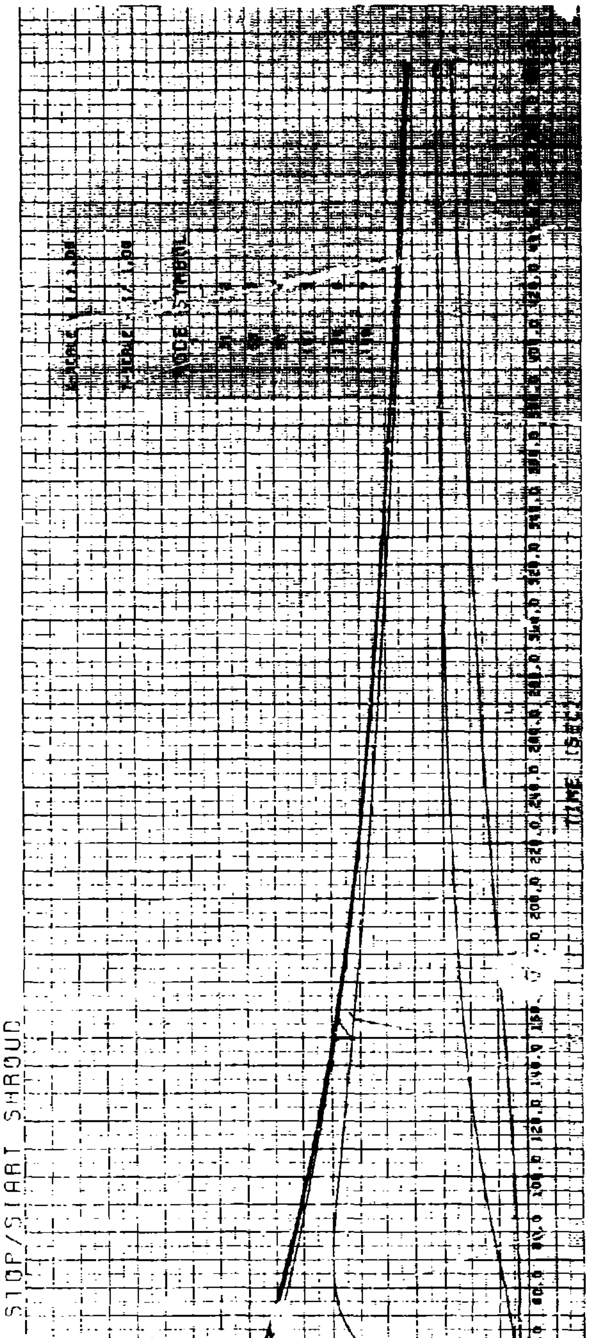


Figure XI-4

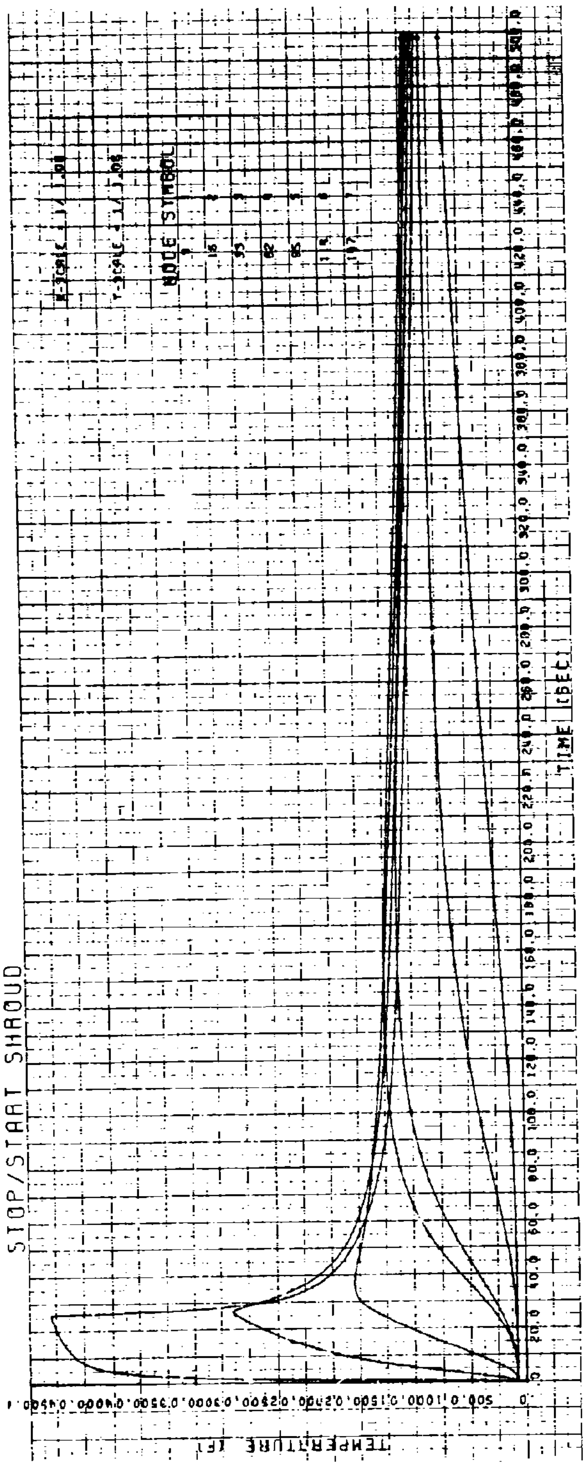


Figure XI-5

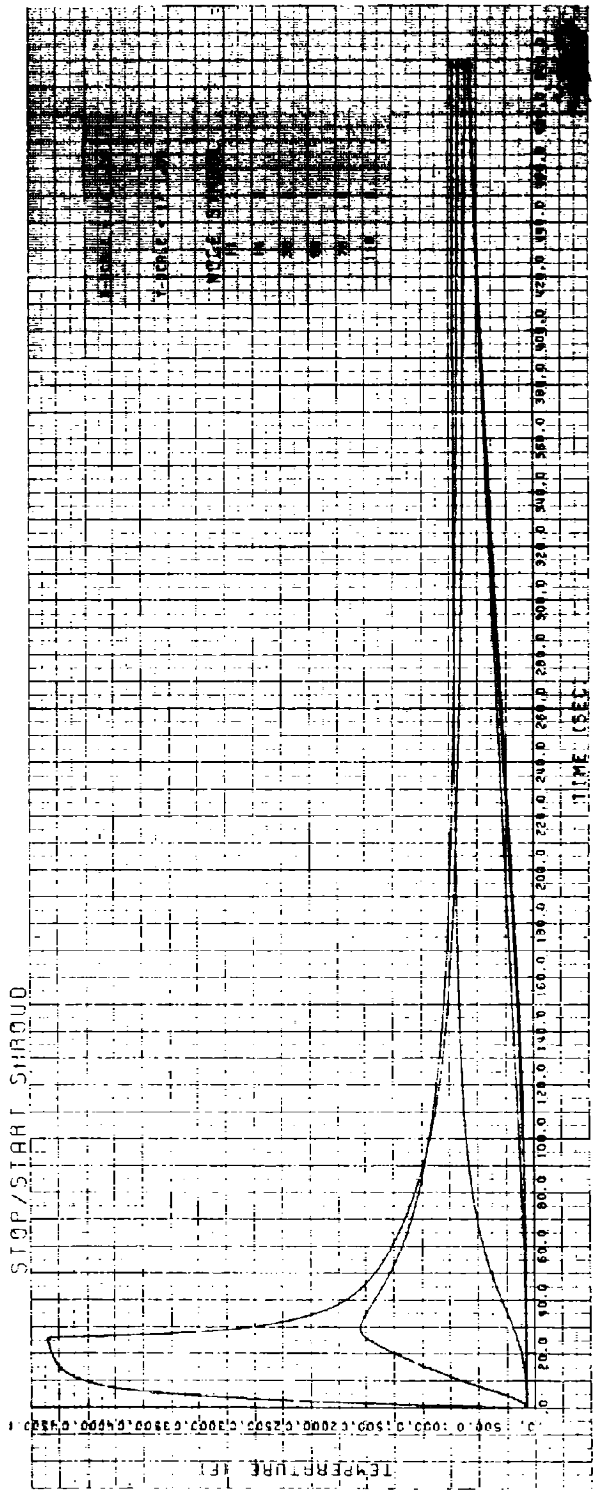


Figure XI-6

APPENDIX E

THERMAL STUDY OF THE SINGLE CHAMBER STOP/START PROPELLANT ENVIRONMENT

SECTION I

INTRODUCTION

The purposes of the thermal analyses of the stop/start motor propellant environment were to predict: (1) the incident radiation flux to the propellant and (2) the pyrolysis gas evolution rate during the "soak" period following pulse action of the motor. These predictions are then to be used in propellant reignition studies. The methods used in performing this study are outlined.

SECTION II

DISCUSSION

The significant parameters which determine the reignition of propellants in stop/start motor environment include the incident radiation flux distribution to the propellant and the pyrolysis gas evolution rates from the motor insulation system. Since both the insulation surface temperature and the energy stored in the insulation increase with pulse duration, the radiation flux to the propellant during "soak" periods will also increase with pulse action time. In the present study the pulse duration considered was 8.3 sec which corresponds to approximately one-third of the total motor action time. Further, the exposed area of the insulation surface and the radiation view factors vary with total motor action time. For this reason the propellant environment was predicted for propellant burn-back conditions corresponding to each of three 8.3 second pulses.

The procedure followed in defining the environment of the propellant was first to predict the response of the internal insulation at representative locations in the motor. For this phase of the study, the chamber wall was divided into regions according to exposure time and magnitude of the local convective heat transfer coefficients. The response of the insulation at each of these regions was then calculated using a computer program. This program utilized the thermal response of elastomeric insulation materials which decompose in depth when exposed to the environment associated with solid rocket chamber environment.

II, Discussion (cont.)

The incident radiation to the propellant grain was then obtained by summing the individual contributions of the various regions of the chamber insulation.

A summary of the results of this study is presented in Figures E-1 through E-5. Figure E-1 shows the calculated incident heat flux at a typical forward propellant station for the soak periods following each of the assumed pulse durations. It will be seen from this figure that the initial rate at which the incident heat flux decreases is large compared to that for later times. This characteristic is due to the fourth-power temperature dependence of radiation and the rapid decay in source (insulation) surface temperature. The insulation material, V-4010, and other elastomeric insulation materials have (1) low conductivity, (2) low char density, and (3) a high yield of pyrolysis gas from the virgin material. These properties are desirable in applications where the attainment of low heat flux to the propellant grain is necessary because they result in a rapid decay in insulation surface temperature. The calculated response of V-4010 at a typical location, as shown in Figure E-6, illustrates this characteristic.

The incident heat flux to typical propellant locations in the aft motor section are shown in Figure E-2. These results exhibit characteristics similar to those shown in Figure E-1 for the forward stations. The magnitudes of incident heat flux in the aft region are somewhat greater, however, due to the more severe environment of the insulation durain action time and a small radiation contribution by the components in the throat region.

Figure E-3 shows the calculated propellant surface temperature variation at typical forward propellant stations for the heat fluxes shown in

II, Discussion (cont.)

Figure E-1. It will be noted in this figure that the propellant surface temperature decreases continuously.

Figure E-4 shows the propellant surface temperature response for the typical aft propellant stations. These results exhibit characteristics similar to those for the forward stations. As noted above, the environment is slightly more severe and the propellant surface temperatures are correspondingly higher.

Figure E-5 shows the total mass evolution rates of the insulation pyrolysis gas for the three "soak" periods considered. It will be noted from this figure that the pyrolysis gas evolution rate decreases with time for each of the "soak" periods, and that the magnitude of the evolution rate for equal "soak" periods increases with total action time. The latter characteristic is due to the increase in exposed insulation area with action time.

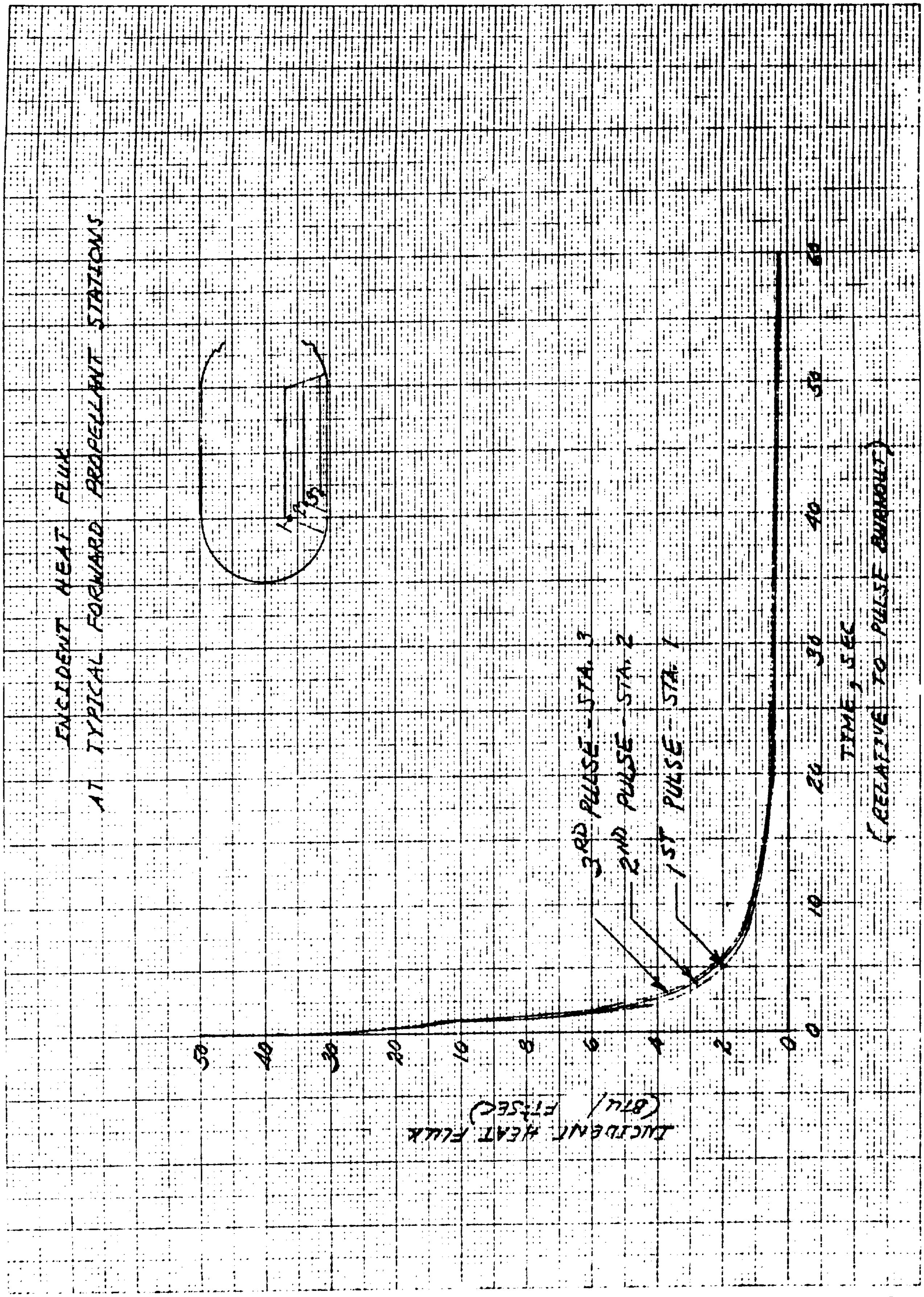


Figure E-1

Preceding Page Blank

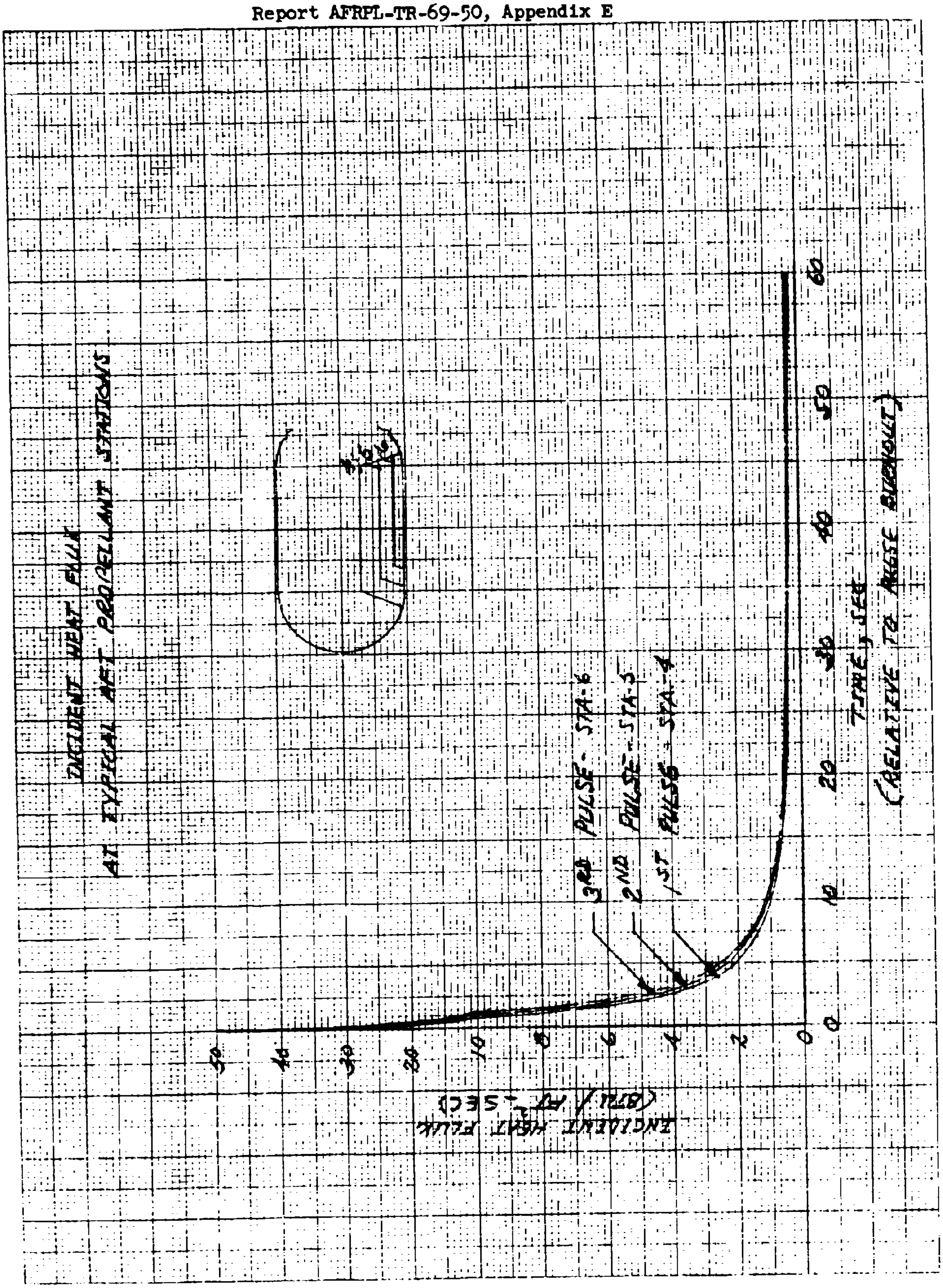

INCIDENT HEAT FLUX
AT TYPICAL AFT PROPELLANT STATIONS
3RD PULSE - STA-6
2ND PULSE - STA-5
1ST PULSE - STA-4
INCIDENT HEAT FLUX
(BTU/FT²-SEC)
0
2
4
6
8
10
20
30
40
50
TIME, SEC
(RELATIVE TO PULSE BURNOUT)
0
10
20
30
40
50
60

Figure E-2

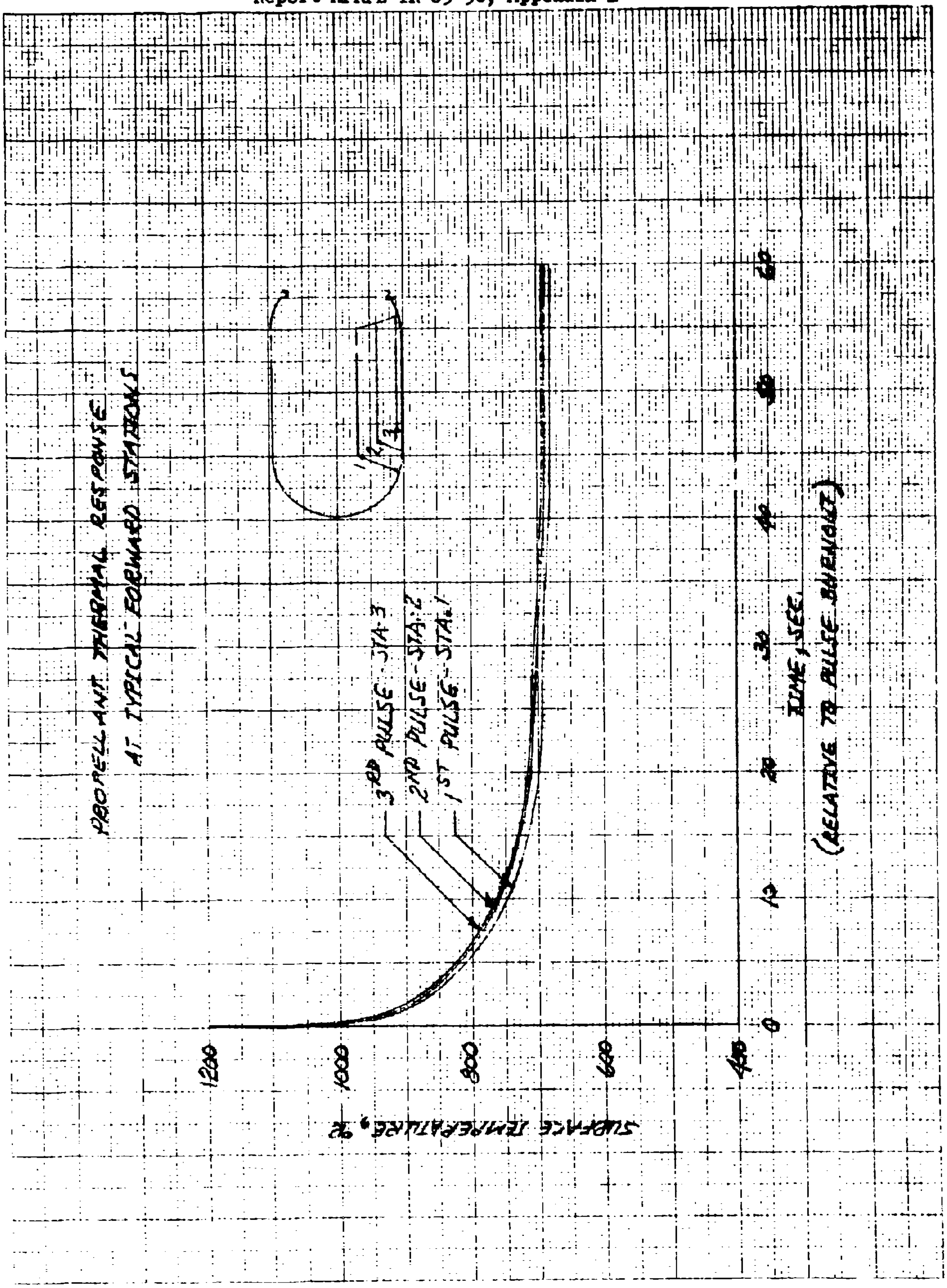

PROPELLANT THERMAL RESPONSE
AT TYPICAL FORWARD STATIONS
3RD PULSE - STA 3
2ND PULSE - STA 2
1ST PULSE - STA 1
1
2
3
SURFACE TEMPERATURE, °R
1200
1000
800
600
400
0
10
20
30
40
50
60
TIME, SEC
(RELATIVE TO PULSE BURNOUT)

Figure E-3

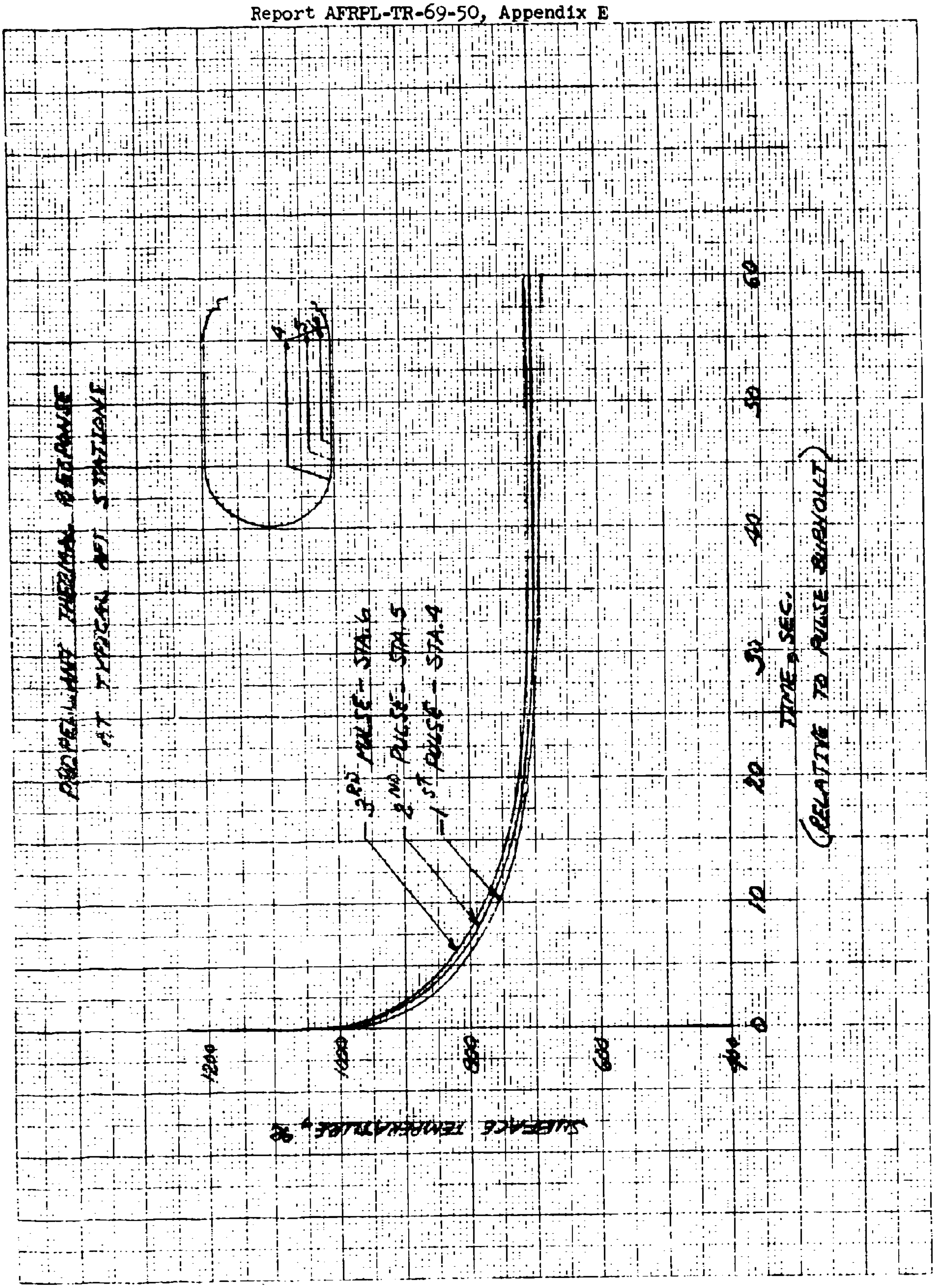

PROPELLANT THERMAL RESPONSE
AT TYPICAL AFT STATIONS
3RD PULSE - STA.6
2ND PULSE - STA.5
1ST PULSE - STA.4
TIME, SEC.
(RELATIVE TO PULSE BURNOUT)
SURFACE TEMPERATURE, °R
1200
1000
800
600
400
0
10
20
30
40
50
60
4
5
6

Figure E-4

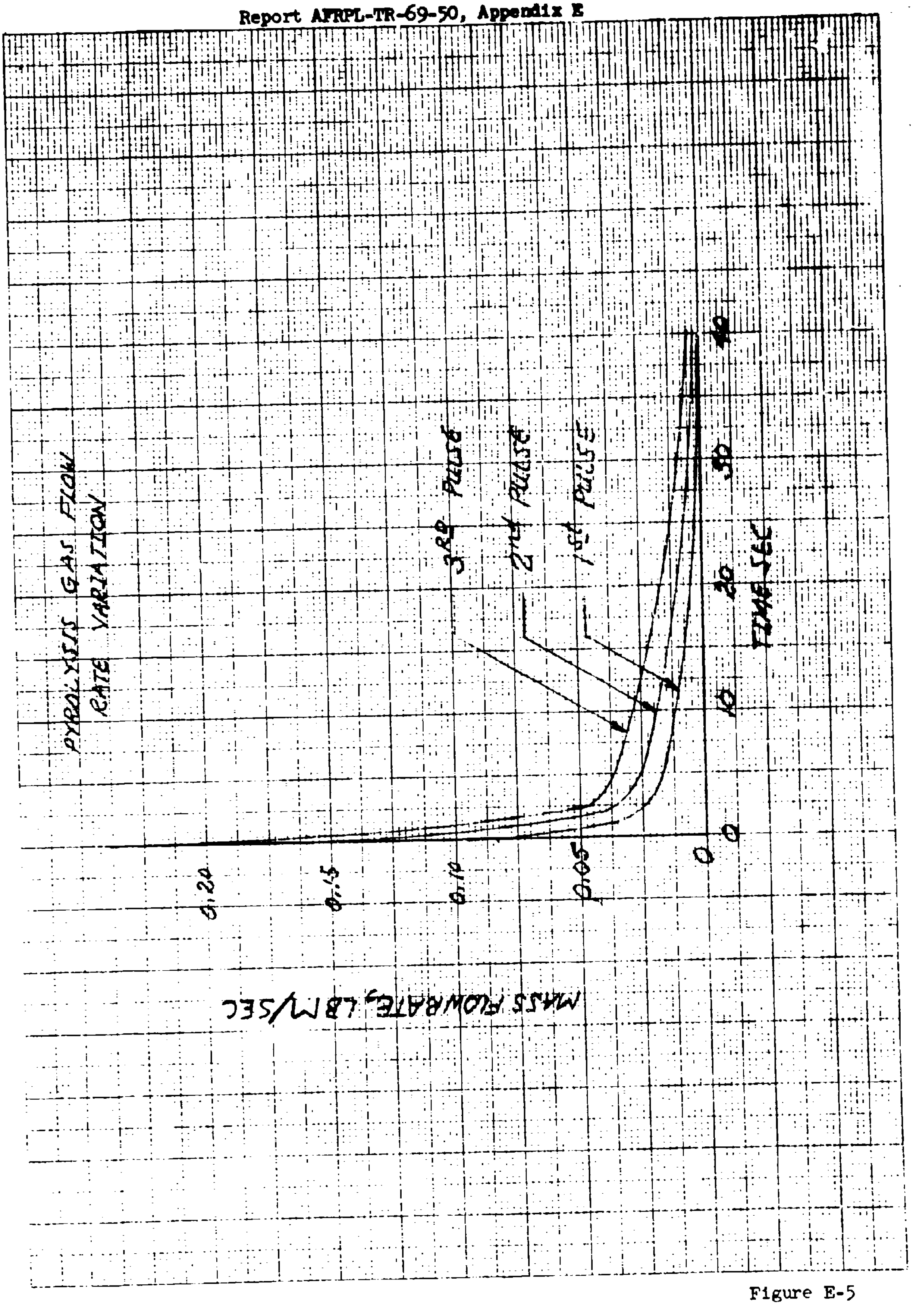

PYROLYSIS GAS FLOW
RATE VARIATION
3RD PULSE
2ND PULSE
1ST PULSE
TIME SEC
MASS FLOWRATE, LBM/SEC
0
10
20
30
40
0.05
0.10
0.15
0.20

Figure E-5

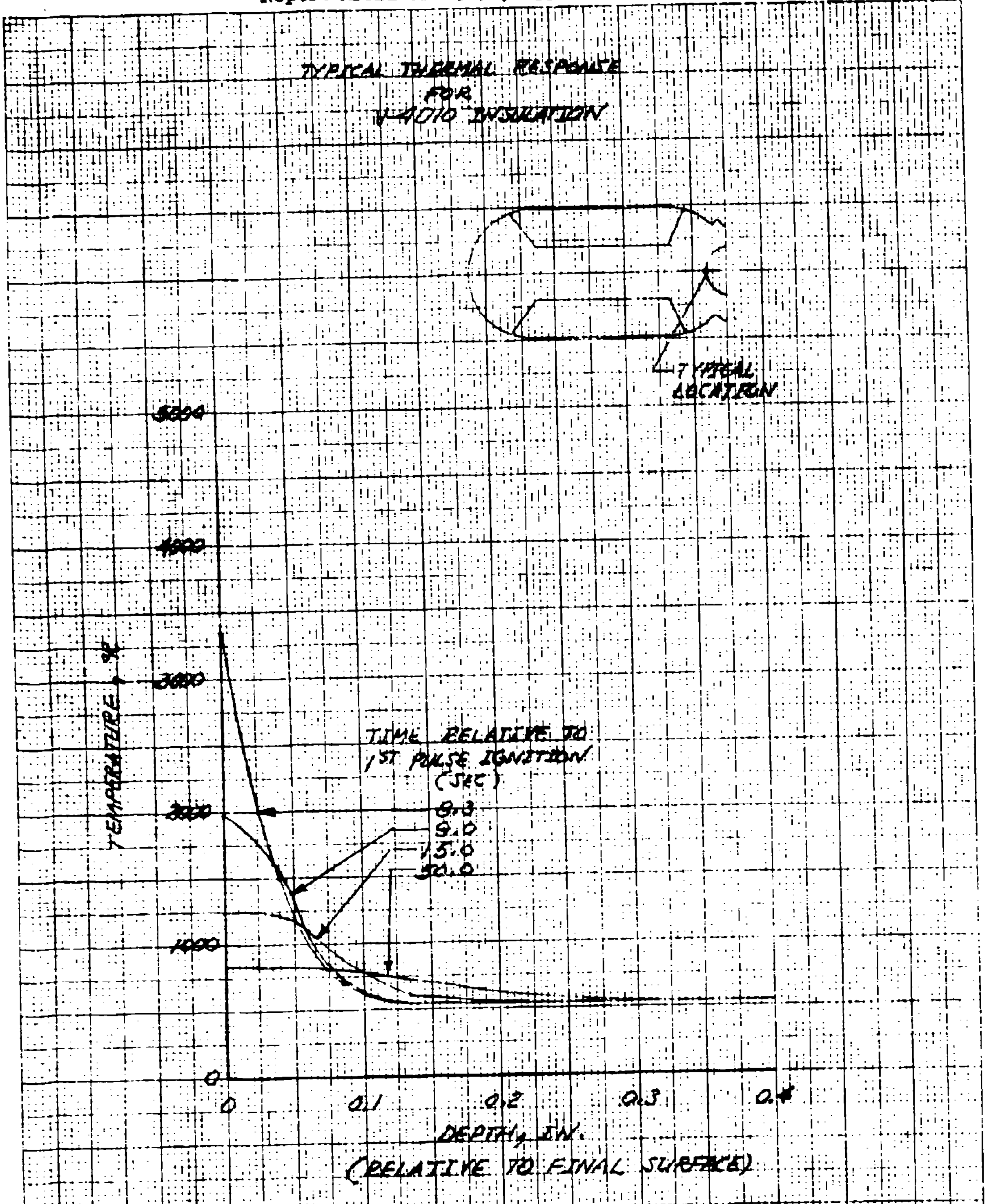

TYPICAL THERMAL RESPONSE
FOR
V-4010 INSULATION
TYPICAL
LOCATION
5000
4000
3000
2000
1000
0
TEMPERATURE, °F
TIME RELATIVE TO
1ST PULSE IGNITION
(SEC)
8.3
9.0
15.0
50.0
0
0.1
0.2
0.3
0.4
DEPTH, IN.
(RELATIVE TO FINAL SURFACE)

Figure E-6

APPENDIX F

RE-IGNITION ANALYSIS OF THE SINGLE-CHAMBER STOP/START CONTROLLABLE SOLID ROCKET MOTOR

SECTION I

INTRODUCTION

A re-ignition analysis has been conducted of the stop/start motor to determine if motor re-ignition could occur after a pulse termination. The analysis was based on the results of Appendix E.

SECTION II

DISCUSSION

Rocket motor ignition phenomena are analyzed through the use of ignitability data derived from tests conducted in the arc-image furnace under controlled environmental conditions. From these tests, time to ignition for a particular propellant is defined in terms of induced heat flux and pressure. In addition, propellant critical ignition pressure is determined through the use of the furnace where critical pressure is defined as the highest pressure at which the time-to-ignition is considered infinite. After the test data is obtained, it is placed through a smoothing process and scaling laws developed for extrapolation to other flux levels.

Internal motor pressure is derived from insulation pyrolysis and propellant ablation due to the thermal and pressure environment. These data are shown in Appendix E.

SECTION III

THEORY

The general ignition theory considers the induced heat flux and the temperature profile in the solid propellant grain. Heat is transferred to the propellant grain by convection and radiation modes. For this motor, the means of heat transmission is principally by radiation. Time to propellant ignition, t_{π}, is defined as the summation of the thermal induction interval, t_o, and the chemical induction interval, t_c. The thermal induction period is defined in terms of heat flux, propellant diffusivity, conductivity, auto-ignition, bulk temperature, and a critical propellant depth. The critical depth is a characteristic depth to which the propellant must be raised to auto-ignition temperature for sustained ignition to occur. The chemical induction period is defined in terms of the critical pressure, local pressure, and an empirical constant determined from arc-image data.

SECTION IV

DISCUSSION

A curve fit of the propellant ignitability data was made after a smoothing process. Particular emphasis was placed on assuring a good fit on the lowest heat flux curve since Appendix E shows a low flux environment in the motor. Time to ignition for any heat flux may be found from,

$$t_{ig} = t_o + t_c$$

$$t_{ig} = \frac{\ln \dot{q} - \ln \left(\dot{q} - 0.21977\ (490 - T_{amb})\right)}{40.568} + \frac{1}{0.65\ (P - 45)}$$

where: t_{ig} = seconds

$\dot{q}$ = Btu/ft^2-sec

T_{auto} = 490°F

P^* = 45 psia

By inspection, it is seen that there are two quantities which tend to make t_{ig} approach infinity:

(1) $\dot{q} - 0.21977\ (490 - T_{amb}) = 0;\ \ln o = -\infty$

(2) $P - 45 = 0;\ \lim_{P \to 45} \frac{1}{P-45} = \infty$

The critical depth has been found to be approximately 0.004 inch. Figure D-1 shows that for any pulse time there is a steep temperature gradient in the solid propellant and that at a depth of 0.004 inch the local temperature is below the autoignition temperature.

Figures E-1 and E-2 of Appendix E show that incident heat flux is at a maximum when t = 0 and decreases extremely fast with increasing time. The mean heat flux for the first 0.500 second is approximately 25 Btu/ft^2 -sec. Using this information and propellant ignitability data, with an assumed

IV, Discussion (cont.)

chamber pressure of 2.0 psia due to insulation and propellant pyrolysis, the propellant ablation rate is found to be approximately 40×10^{-4} in./sec. Normally, the incident heat flux would be determined for all locations on the propellant grain and the effects on ablation rate integrated over the total mass flow. Since the motor configuration is relatively complex, this approach was not deemed feasible. Thus, for a first approximation, the maximum flux was considered to exist in all locations over the complete propellant surface. This approximation will yield a conservative answer with respect to re-ignition. Induced pressure is found by summing the mass flow from all sources and assigning an overall mass flow coefficient to the gases. For any pulse, the maximum pyrolysis occurs near t = 0, where t is the time after normal burning termination. Also, from Appendix E, the induced heat flux is independent of pulse, therefore the maximum mass flow occurs after the last pulse where maximum surface area occurs. The induced pressure is found as follows:

$$P = \frac{\sum \dot{W}}{A_t C_w} = \frac{1}{A_t C_w} \left(\rho r_a A_b + \dot{W}_{pyrolysis} \right)$$

A_t = throat area, 39 in.^{2}

ρ = density, lbm/in.^{3}

r_a = ablation rate, in./sec

A_b = total propellant surface area, in.^{2}

C_w = assumed flow coefficient, lbm/lbf-sec

$$P = \frac{1}{39(0.012)} \left(0.063\,(0.004)\,(1400) + 0.175 \right) = 1.13 \text{ psia}$$

$$P < 2.0 \text{(assumed)}$$

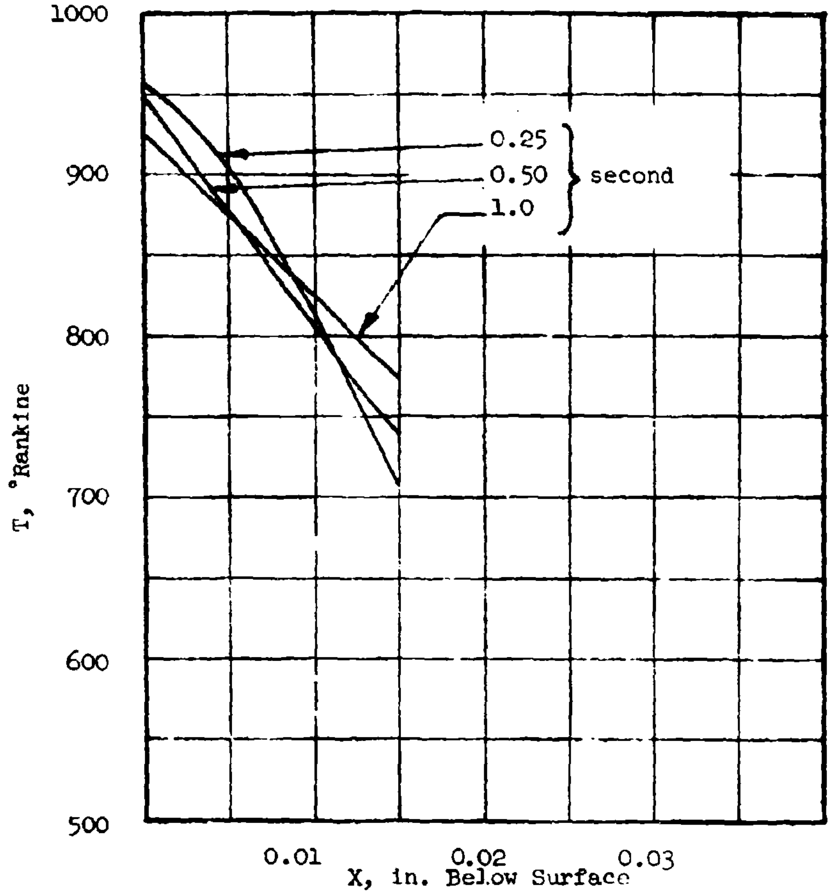
SECTION V

CONCLUSIONS

Based on results of Appendix E and this study, it may be concluded that re-ignition will not occur for the motor configuration as designed. In the predicted thermal environment within the motor, none of the requirements for ignition are satisfied, as shown below.

Quantity	Maximum Predicted Value	Critical Value
$P_{induced}$, psia	1 - 2	45
$\dot{q}_{induced}$, Btu/ft^2-sec	35	91

Although there have been several simplifying assumptions made in this analysis, it should be noted that each would tend to provide more favorable ignition conditions than actually exist. Thus, all estimates are conservative assuring that re-ignition will not occur.



Single Chamber Stop/Start Motor
Propellant Temperature vs Depth

Figure F-1

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) AEROJET-GENERAL CORPORATION P. O. Box 15847 Sacramento, California 95813	2a. REPORT SECURITY CLASSIFICATION CONFIDENTIAL
	2b. GROUP 4

3. REPORT TITLE

(Unclassified Title)

Single-Chamber Stop/Start Solid Rocket Motor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report April 1968 through February 1970

5. AUTHOR(S) (First name, middle initial, last name)

Charles T. Levinsky
Norman P. Mittermaier
Albert O. Hardrath

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1970	505	

8a. CONTRACT OR GRANT NO. F04611-68-C-0063	9a. ORIGINATOR'S REPORT NUMBER(S) None
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL, (RPPR/STINFO), Edwards, California 93523.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Rocket Propulsion Laboratory Edwards, California 93523

13. ABSTRACT

This report deals with the technical effort conducted during the fulfillment of Contract F04611-68-C-0063, "Single-Chamber Stop/Start Solid Rocket Motor." The program comprised five phases made up of preliminary design, propellant tailoring, component testing, lightweight motor design, and lightweight motor fabrication and testing.

Although some problems were encountered in pintle nozzle and igniter function, the program yielded some very significant results. The basic design concepts of the motor were demonstrated to be sound and practical. The functional problems encountered are identified and solutions are presented to eliminate them.

The program clearly demonstrated that a lightweight solid rocket motor can be repeatedly stopped and started at a simulated altitude of 60,000 ft and that a wide diversity of duty cycles can be attained to meet the spectrum of potential mission requirements.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Stop/Start						
Single-Chamber						
Movable Pintle Nozzle						
Pulse Igniter						
Cold Flow						
Static Test Firing						
Burning Rate						
Burning Rate Exponent						

UNCLASSIFIED
Security Classification